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The local terrestrial effects of salt aerosol drift from powered spray modules and a mechanical draft cooling tower at Turkey Point, Florida were evaluated through field and controlled exposure studies. Indigenous vegetation, soil and fresh water were sampled over a year long period to acquire pre-activation baseline data and to provide for the assessment of possible environmental impact of salt aerosol loading from the test cooling devices. No measurable effects attributable to salt aerosol emissions from test cooling devices were detected on indigenous plants, soil or fresh water sampled during or following operation of the test cooling tower/spray modules.

The introduced cultivar plants showed visible foliar injury and elevated salt concentrations, correlated to the combined influences of cooling device and east wind drift exposure, only at the exposure site closest (215M) to the cooling tower/spray modules.

Full-term effects and salt aerosol tolerance levels of a cultivar plant, bush bean, were examined by controlled exposure to a simulated sea-salt aerosol at concentrations representative of the Turkey Point test site. The trace injury threshold of the bush bean trifoliate leaf was at a salt aerosol concentration of 5 $\mu g/m^3$ for 100 hours cumulative exposure over a four week period, while pod productivity was reduced at salt aerosol concentrations of 25 $\mu g/m^3$ and 75 $\mu g/m^3$ at the environmental conditions of the exposure study.

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EPA-600/3-76-078
July 1976

ECOLOGICAL EFFECTS OF AEROSOL DRIFT FROM A SALTWATER COOLING SYSTEM

by

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ABSTRACT

The local terrestrial effects of salt aerosol drift from powered spray modules and a mechanical draft cooling tower at Turkey Point, Florida were evaluated through field and controlled exposure studies. Indigenous vegetation, soil and fresh water were sampled over a year-long period to acquire pre-activation baseline data and to provide for the assessment of possible environmental impact of salt aerosol loading from the test cooling devices. No measurable effects attributable to salt aerosol emissions from test cooling devices were detected on indigenous plants, soil, or fresh water sampled during or following operation of the test cooling tower/spray modules.

Cultivar plants were sited at varying distances to identify and characterize the influence of sea salt aerosol drift from the test cooling devices. The introduced cultivar plants showed visible foliar injury and elevated salt concentrations, correlated to the combined influences of cooling device and east wind drift exposure, only at the exposure site closest (215M) to the cooling tower/spray modules.

Full-term growth effects and salt aerosol tolerance levels of a cultivar plant, bush bean, were examined by controlled exposure to a simulated sea-salt aerosol at concentrations representative of the Turkey Point test site. The trace injury threshold of the bush bean trifoliate leaf was at a salt aerosol concentration of 5 $\mu g/m^3$ for 100 hours cumulative exposure over a four week period, while pod productivity was reduced at salt aerosol concentrations of 25 $\mu g/m^3$ and 75 $\mu g/m^3$ at the environmental conditions of the exposure study.

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SECTION I

CONCLUSIONS

No measurable effects attributable to salt aerosol emissions from test cooling devices were detected on indigenous plants, soil, or local fresh water sampled during or following operation of the test cooling tower/spray modules.

Introduced bush bean and sweet corn plants at Turkey Point showed visible foliar injury and high salt concentrations only at the exposure site closest (215 m) to the cooling tower/spray modules.

For those bean and corn plants within 215 m of the cooling devices, salt concentration correlated significantly with the duration of exposure to cooling tower/spray module and east wind salt aerosol drift.

Leaf injury to bush bean plants in controlled exposure studies was directly proportional to salt aerosol concentration and foliar salt accumulation.

The trifoliate leaves of plants five weeks old at initial exposure in controlled exposure studies were more susceptible than the trifoliate leaves of one and three week old plants exposed to the same salt deposition.

The dose threshold for trifoliate leaf injury to the bush bean was at a salt aerosol concentration of 5 $\mu g/m^3$ for 100 hours cumulative exposure over a four week period beginning at fifth week of growth.

Exposure to a salt aerosol concentration of 75 $\mu g/m^3$ for 100 cumulative hours over a four week period significantly reduced the fresh and dry weight of the upper trifoliate leaves of bush bean plants five weeks old at initiation of exposure.

One week-old plants exposed to salt aerosol concentration of 25 $\mu g/m^3$ and 75 $\mu g/m^3$ for 100 cumulative hours of controlled exposure showed reduced pod production and yield, whereas the productivity of three and five week-old plants showed no effect.

Sodium was translocated from the trifoliate leaf of test bush beans to other plant parts independent of and comparatively faster than was chloride.

Microscopic examination of injured leaves by salt aerosol revealed that the chloroplasts below the upper epidermis disintegrated and lost their identity. Crystals were observed below the epidermis layer, between palisade cells and near the vascular bundles. These crystals resembled sodium chloride in structure.

SECTION II

RECOMMENDATIONS

1. Future field studies should extend over longer periods and provide for a larger number of full-term sampling sites for both indigenous and introduced plants to permit a finer resolution of impact as function of distance from mechanical cooling device. Sample sites should be at least tripled and located in all quadrants from the tower where possible.

2. Better coordination and integration of physical monitoring (air sampling and meteorology) with biological effects assessment is required for meaningful whole systems analysis.

3. Future controlled exposure studies should provide for simulation of full-term, low-level ambient salt aerosol exposure over a 24 hour period as well as transient peak exposures. Salt concentrations applied should represent total ambient loading anticipated from full complement of mechanical cooling units.

SECTION III

INTRODUCTION

BACKGROUND

General Considerations

Legal restrictions and environmental consequences have made once-through cooling power plants an increasingly unattractive option to dissipation of thermal waste associated with each new steam electric power facility constructed by the utilities. Closed system evaporative cooling devices, such as cooling towers, spray modules, and cooling canals, have become more attractive available alternatives to electric utilities in minimizing the environmental impact of thermal effluents. Recent Federal Power Commission projections suggest that from 35% to 50% of new power generating installations constructed from 1976 to 1980 will utilize cooling towers. Scarce fresh water resources make consideration of brackish and sea water as cooling media imperative. However, the current knowledge and understanding of potential and real environmental impact of saline aerosol drift is sketchy and tentative. The intent of this report is to make some modest contribution to the effort being made to characterize the ecological impact of saline aerosol drift from closed system evaporative cooling devices.

Assignment of Task

In 1973, the Office of Enforcement and General Counsel of the U. S. Environmental Protection Agency tasked the National Ecological Research Laboratory (NERL) to assess the terrestrial ecological effects of aerosol drift from salt water mechanical cooling devices being tested at the Florida Power and Light nuclear power plant complex at Turkey Point, Biscayne Bay, Florida. The ecological studies were initiated in October 1973. The Thermal Branch of The National Environmental Research Center, Corvallis, Oregon directed the concurrent salt aerosol drift sampling program and published the following reports (1) Drift Data Acquired on Mechanical Salt Water Cooling Devices, EPA-650/2-75-060 and (2) Effect of Cooling Devices on Ambient Salt Concentrations, EPA 600/3-76-032. This final report documents the finding of that assessment and constitutes one part of the multi-faceted study required for final judgment of the U. S. vs Florida Power and Light consent decree.

Location

The Florida Power and Light, Turkey Point Nuclear Power Plant complex is located about 48 kilometers south of Miami, Florida (Figure 1A). The cooling tower site was about 2.5 kilometers west of Biscayne Bay (Figures 1B & 2). There were two closed system cooling devices being tested during this project. One system was a one cell Marley 600/700 mechanical draft tower (Figure 3) with a water circulation rate

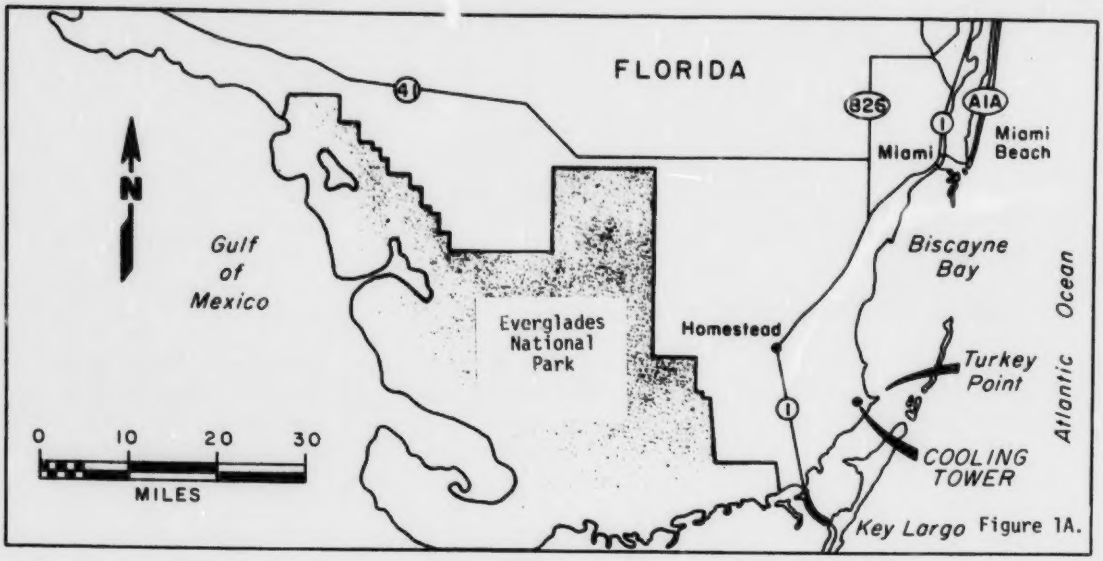

FLORIDA
41
826
A1A
1
Miami
Miami Beach
N
Gulf of Mexico
Everglades National Park
Homestead
Biscayne Bay
Turkey Point
COOLING TOWER
Atlantic Ocean
0 10 20 30
MILES
Key Largo

Figure 1A.

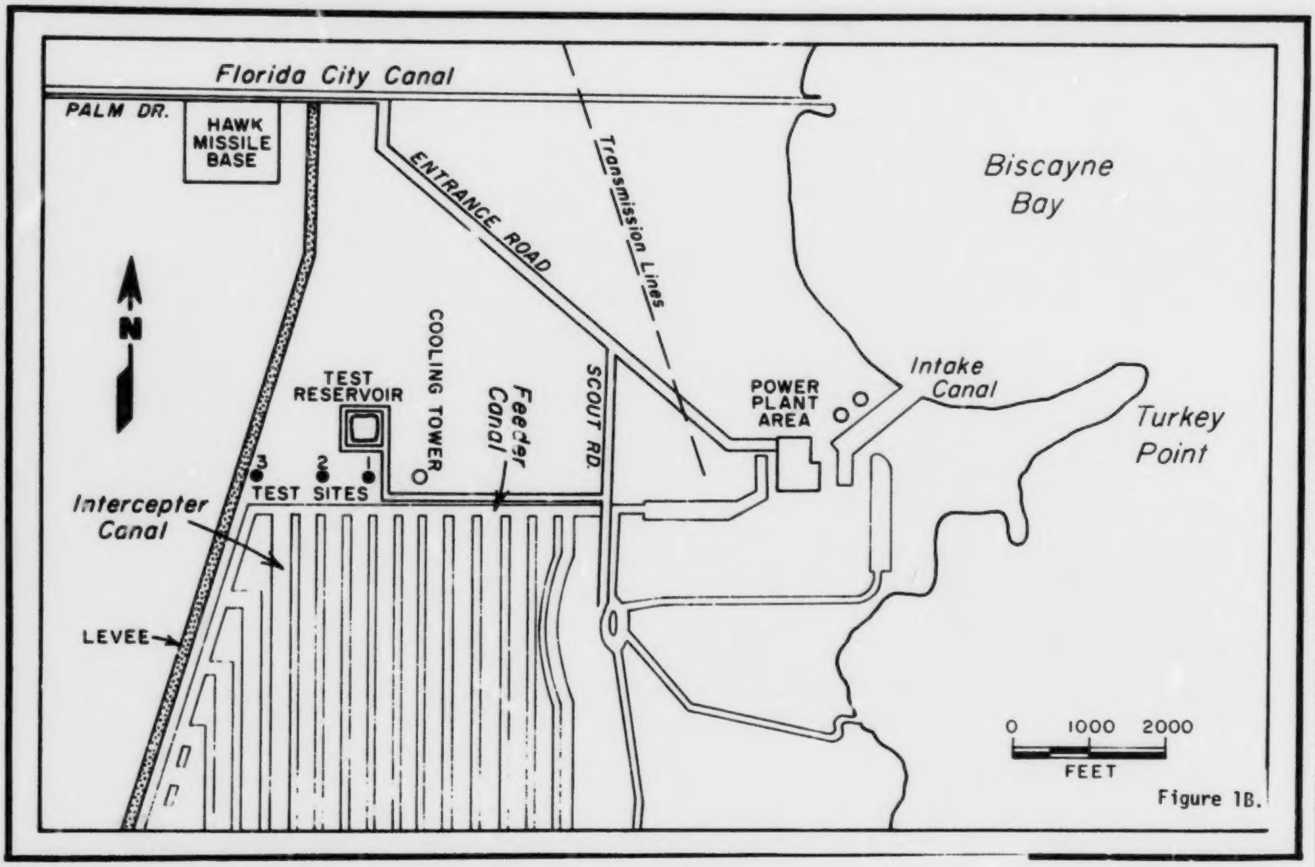

Florida City Canal
PALM DR.
HAWK MISSILE BASE
ENTRANCE ROAD
Transmission Lines
Biscayne Bay
N
COOLING TOWER
SCOUT RD.
TEST RESERVOIR
Feeder Canal
POWER PLANT AREA
Intake Canal
Turkey Point
3
2
1
TEST SITES
Intercepter Canal
LEVEE
0 1000 2000
FEET

Figure 1B.

Figure 1. **NUCLEAR POWER PLANT AT TURKEY POINT**

Figure 2. The Florida Power and Light's Turkey Point site. Mechanical draft cooling tower at the mid-ground and airborne particulate sampler (APS) Station in foreground. The body of water is part of a feeder canal. Power spray modules (PSM) visible in far right background.

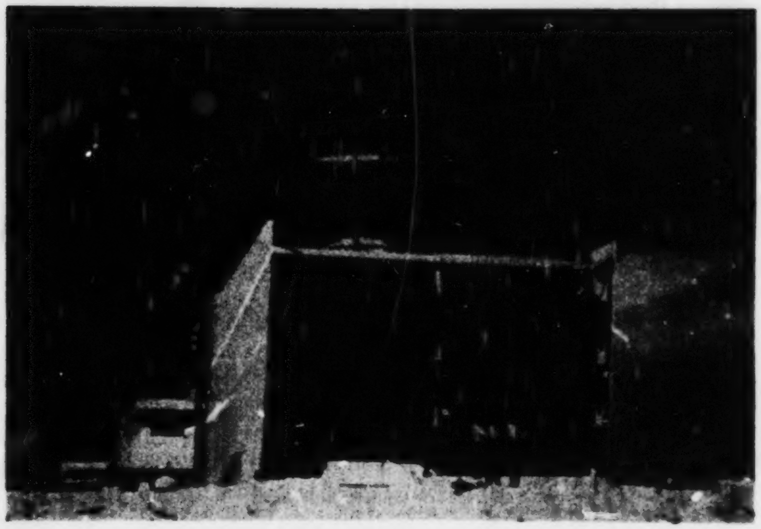


Figure 3. Marley 600/700 mechanical draft cooling tower at Florida Power and Light's Turkey Point Site. Drift eliminators visible on south side of tower.

of 4,500 m^3/hr (2 x 10^4 gpm). The other system was a powered spray module (PSM) system with a water circulation rate of 4,500 m^3/hr (Figures 4 and 5). The spray modules were located in the feeder canal immediately adjacent to the cooling tower. Both of these systems were operated only in test modes and were not necessary for cooling of the functioning reactor piles (Figure 6). The continual cooling requirement for the generating plant was provided by an extensive closed salt water canal system.

LITERATURE REVIEW

Natural Source of Ambient Airborne Salt

The ocean surface serves as the principal, global-scale natural source of airborne salt aerosol and particles. The airborne salt is introduced into the lower few centimeters of the atmosphere through a bubble-injection mechanism. Generated by the wave action of white caps and breaking surf, foam bubbles bursting through the ocean surface inject small sea water droplets into the air. Some of these injected droplets remain airborne to be distributed deeper into the atmosphere through turbulent mixing and are carried inland by onshore winds. Once particles achieve a quasi-equilibrium over a long fetch, the particles might reach considerable distances inland. Concentrations on the order of 1 $\mu g/m^3$ airborne sea salt particles have been reported in the Midwestern U.S. (1). However, the bulk of the airborne particles are rapidly depleted as they are deposited by sedimentation, impacted on obstacles, or washed-out by precipitation once reaching land, describing a nearly exponential deposition curve.

Cooling Tower Airborne Salt Increment

There are a variety of diverse predictive salt deposition models that can be utilized to describe the incremental salt loading from cooling towers. The models lack extensive field validation and currently there does not appear to be any favored, established modeling technique. Predicted terrestrial deposition rates yielded from the various models can vary an order of magnitude. Also, the necessarily generalized nature of the models does not account for local terrain, which can greatly affect actual site deposition. The current, principal value of models is that they allow an approximation of the extreme limits of salt deposition. Despite the modeling variations in quantification of actual deposition amounts, determination of the comparative contribution and geometry of cooling tower salt deposition show the models to be in broad agreement. Most computational techniques predict that salt drift can approximate ambient levels found a short distance inland under conditions of high humidity and low wind speed. Where the humidity is low (less than 70%), the cooling device increment at any particular location could be a factor of 10 smaller than ambient (2). As might be anticipated, all the techniques describe a long term terrestrial salt deposition which rises abruptly to a maximum in close proximity to the source, then gradually decays to background levels with increased

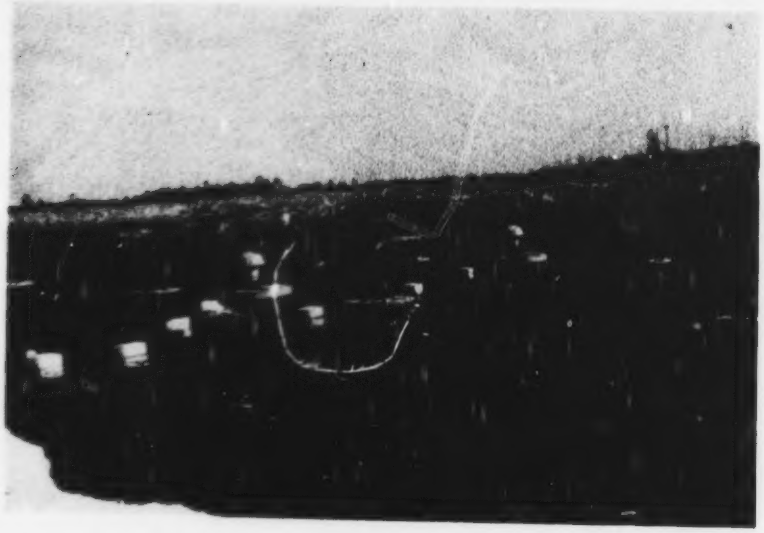


Figure 4. Powered spray modules (PSM) - two pumps and eight spray nozzles, the body of water is a feeder canal adjacent to cooling tower.

Figure 5. Power spray modules in operation.

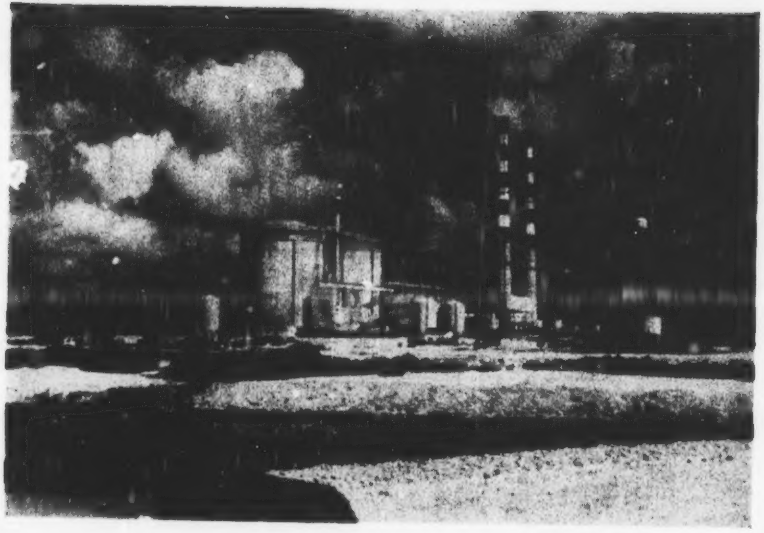


Figure 6. The Florida Power and Light's Turkey Point reactor site.

distance. The powered spray modules deposit a higher fraction of generated drift in close to the site location, while the deposition decay with distance is much greater than that of current cooling towers of comparable circulation rates (3).

Factors of Foliar Salt Deposition

The severity of plant foliar injury from airborne salt is broadly related to the quantity of salt deposited and the length of time the salt remains on the leaf. The rate of salt deposition per unit leaf surface is largely determined by the airborne salt concentration, settling velocity, surface roughness factors, wind velocity and persistance. Wind exposure can have pronounced effects on the quantity of salt collected by a plant.

Measurements taken with glass slide collectors at different relative positions near seashore plants subjected to wind salt deposition showed an order of magnitude difference in collection rates. Leaves on the windward edge of the indigenous bush canopy had impaction rates of 4 mg/m^2-hr, while those on the leeward side had a collection rate of only .4 mg/m^2-hr (2). The larger fraction of airborne salt is deposited by impaction, rather than sedimentation due to settling in shoreline areas (4). Not only is the rate of impaction increased with increased wind speed, but greater volumes of air are swept across greater amounts of plant surface area. This not only increases the severity of injury, but increases the incidence of injury on the plant.

Factors of Foliar Salt Accumulation

Humidity as well as precipitation frequency and amount are factors which affect foliar salt accumulation. Rain can abruptly reduce salt build-up on vegetation, while simultaneously lowering the airborne salt concentration through wash-out. Local rain wash-out can, in some instances (e.g., tropical cyclone), be offset by the contribution of increased gradient wind over long ocean fetches which allow a build-up of salt concentrations in rainfall and increased salt aerosol generation due to greater wave action (5).

With increased hydration, the adherent and penetrating characteristics of salt particles also increase. Swain found that no substantial uptake of foliar applied salt occurred beyond the first post-exposure hour by bush beans under low humidity conditions. On the other hand, for plants exposed and maintained under high humidity conditions the foliar uptake period was extended an additional 8 to 24 hours, though at a reduced rate (6). McCune et al., reported bush beans subjected to relative humidities of 50 to 70% during and following exposure required twice the salt aerosol dose to produce equivalent injury as those plants exposed to 85% relative humidity. Though no quantitative comparisons were conducted, similar studies found dry salt aerosol much less toxic than mist. The authors attributed this increased toxicity to the deliquesent property of NaCl near 75% relative humidity allowing increased foliar penetration (7).

Detrimental Levels of Airborne and Foliar Salt Concentrations

Sea water consists primarily of NaCl, but it also contains small amounts of $MgCl_2$, $MgSO_4$, $CaSO_4$, as well as K_2SO_4, $CaCO_3$ and MgBr. Iodine, zinc, manganese, copper and noble metals are present as trace elements. Investigators (8, 9, 10, 11, and 12) have shown that aerosol containing salt, especially sea salt, can damage plants, Salt injury normally begins at the margins and base on broadleaves. Tip and marginal necrosis is the most common characteristic symptom of lower levels of foliar salt injury. When plants are subjected to slightly higher doses, the characteristic injury is expressed as interveinal chlorosis, and occasionally necrosis, with possible growth suppression and leaf curl. The entire exposed leaf surface can become necrotic within a few hours after exposure to extreme salt concentrations. In the Northeastern U.S., field symptoms of acute injury are not usually observed on indigenous coastal vegetation at airborne salt concentrations below 40 $\mu g/m^3$, though growth distribution can be affected at concentrations above 10 $\mu g/m^3$ (13).

Garber (14) found that spraying beans and lettuce with a 5 percent salt solution caused very severe damage. Concentrations as low as 0.5 to 1.0 percent sea salt have injured plants by curling the leaf and causing necrotic areas. Kisser et al., (15) showed that soluble substances such as salt, when sprayed on the upper surface of the leaf, caused the ions of dissolved salt to diffuse through the epidermis into the interior of the leaf. Necrotic spots developed unevenly over the entire surface of the treated leaves. These symptoms indicate that increased salt concentration in the leaf kills the cells at the point of entry. Miwa et al., (16) observed that sea salt spray caused necrosis and loss of leaves and fruit on citrus plants.

A study by Boyce Thompson Institute (17) indicated that pinto bean plants exposed to salt aerosol produced symptoms of tissue collapse followed by necrosis. Marginal wilting occurred in the leaves of plants exposed to a salt aerosol concentration of 900 $\mu g/m^3$ for 30-40 minutes when the major portion of the particle sizes ranged from 100-150 microns. An unpublished report by Moser (4) indicated that exposing bean plants to 100 $\mu g/m^3$ for only 12 hours will result in severe injury, whereas exposure to 10 $\mu g/m^3$ for 48 hours has no detrimental effects.

In his "Chalk Point Cooling Tower Study," Curtis (18) reported that Na^+ and Cl^- observed in injured plant samples collected near the cooling tower were less than those considered generally toxic for most plants (i.e., 2000 ppm Na^+ or 5000 ppm Cl^- on dry weight basis). According to Eaton (19) some species of plants show Cl^- toxicity symptoms at concentrations below 5000 ppm. Leaves of avocado and grapefruit showed Cl^-

toxicity symptoms at levels as low as 2200 ppm and 2600 ppm Cl^-, respectively. Eaton also reported that new growths of apple, peach, and cherry trees were retarded 14, 60 and 60 percent, respectively, by Cl^-, concentrations around 2000 ppm.

Mechanisms of Foliar Salt Injury and Penetration

Morphological studies of salt-stressed plants have indicated reductions in total chlorophyll, chloroplast density, stomatal frequency and intercellular free space, while showing a general leaf thickening and more extensive palisade parenchyma development as a result of that salt exposure (20, 21, 22). Foliar injury caused by lower concentrations of salt accumulation from aerosols appear to disrupt metabolic processes. Results of extensive salt-stress studies by Strogonov revealed severe disturbances of nitrogen metabolism as expressed by a reduction of protein nitrogen content and accumulations of ammonia, amides and free amino acids. The carbohydrate metabolic pathway was also disrupted as evidenced by lowered glucose and fructose concentrations with an accumulation of sucrose and non-productive translocation of various assimilates (23). At high salt concentrations, osmotic plasmolysis appears to occur on the entire exposed leaf surface. The bulk of investigations examining salt inhibition of plant growth found nearly equivalent growth effects of isosmotic solutions of various salts, indicating osmotic effects were primarily involved (6, 21, 24, 25, 26, 27, 28). However, most of these studies employed the root system as the primary absorption avenue rather than leaves and used comparatively high osmotic pressures. Boyce made toxicity comparisons of foliar-applied isosmotic solutions containing a compound of different combinations of sodium, chloride, potassium and sulfate on bush beans. His results indicated chloride was comparatively the most toxic of the ions where the solutions were isosmotic to sea water (29). It has been found, however, that chloride can be translocated comparatively rapidly from the leaves of bush beans, while the salt injury remains localized (30). Whether salt toxicity is a manifestation of specific ion toxicity, osmotic inhibition, or some variable combination of both, remains to be persuasively demonstrated and resolved.

The mechanism of salt penetration through the plant leaf surface is obscure and has not been adequately described. The lipophilic cuticle presents the major epidermal barrier. Thinly cuticled, young bean leaves were found to absorb salt solution much faster than mature leaves. The adaxial surface of the mature foliage was the most impenetrable to salt, while the abaxial surface of the young leaves offered the least resistance (31). The thinly cuticled stomatal cavities may represent the major site of salt penetration, especially in mature leaves (32). In fact Bernstein has postulated that abberant, prolonged stomatal opening produced by salt accumulation might be responsible for the drought-like salt toxicity symptoms of leaves (33). Ion penetration mechanisms (14, 34, 35) and hydrophilic channels (34, 36) are some other possibilities that have been suggested to account for foliar salt penetration. Wind abrasion, insect injury and disease can all injure the cuticular leaf surface, making an intact cuticle a rarity and permitting rapid salt penetration in some natural enviroments.

SECTION IV

GENERAL STUDY APPROACH

RATIONALE

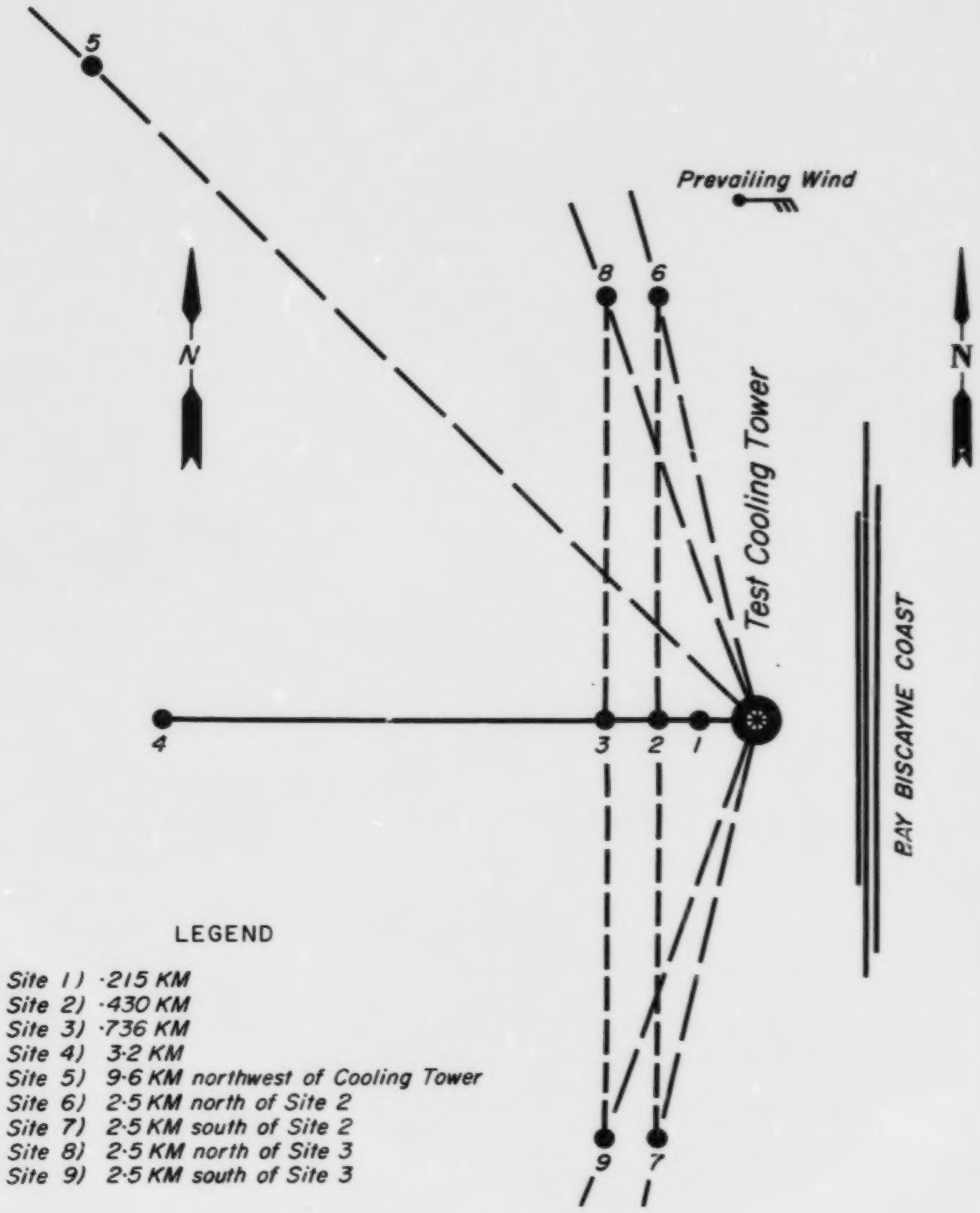
This study was divided into three sequential phases. Each successive phase constituted a logical development of the study's principal intent to characterize the terrestrial impact of incremental salt aerosol loading from test cooling devices. This report has been organized to maintain that sequential division. After briefly outlining the broad intent of each phase the report will elaborate on the design and results of each individual phase in numerical sequence.

Phase I

Phase I was designed to determine the impact of salt aerosol emissions from test cooling devices on selected indigenous vegetation, soil and fresh water. This year-long phase was initiated August 1973 and was not intended to be an exhaustive environmental sampling program, but rather to achieve the most comprehensive short term examination permitted by the external constraints and overall requirements of an on site study. To accomplish this, ambient salt aerosol concentration sampling was undertaken prior to and during operation of the test cooling devices. Samples of native Mangrove leaves, water and soil were collected on a regular basis during the period of study. The information gathered was to help delineate the possible incremental risk of ecological effects posed by the added salt aerosol loadings from the cooling tower and spray modules.

Phase II

Phase II was scheduled from January 15 to March 15, 1974, when the test cooling tower was expected to be in full operation. This phase involved exposures of introduced bean and corn species at varying distances from the tower site. Test crop cultivars were selected on the basis of local representativeness and salt sensitivity. Salt sensitive plants allowed some general characterization of salt aerosol toxicity symptoms that the indigenous halophytic species might not exhibit due to intrinsic adaptive tolerance. An analysis of available climatological data showed that the late winter period is characterized by relatively low rainfall coupled with predominantly easterly, onshore winds. Consequently, it was anticipated that during this season the salt aerosol-stress would be greatest in the vicinity of Turkey Point. Three principal plant exposure sites were located in a line at varying distances downwind and due west of the test cooling tower site. Two additional pairs of plant exposure sites were displaced parallel and to either side of three downwind sites so as to isolate the tower contribution from the natural ambient salt aerosol concentration (Figure 7).


5
Prevailing Wind
8
6
N
N
Test Cooling Tower
BAY BISCAYNE COAST
4
3
2
1
9
7

LEGEND

Site 1) ·215 KM
Site 2) ·430 KM
Site 3) ·736 KM
Site 4) 3·2 KM
Site 5) 9·6 KM northwest of Cooling Tower
Site 6) 2·5 KM north of Site 2
Site 7) 2·5 KM south of Site 2
Site 8) 2·5 KM north of Site 3
Site 9) 2·5 KM south of Site 3

Figure 7. VEGETATION SITE LOCATION

Phase III

Phase III was a controlled exposure study conducted from December 2, 1974, to January 28, 1975. The same variety of bush bean used at Turkey Point was exposed at various stages of growth to three sea salt aerosol concentrations in an exposure facility at Corvallis, Oregon. The concentrations selected were based on combined estimates of approximate background level, incremental cooling tower or powered spray modules (PSM) emissions, and the highest concentration detected at the closest Turkey Point site. The duration of exposure was that which might be expected to occur when incremental drift was directed over the Turkey Point plant sites by the prevailing wind within one month period. The plants were routinely examined for growth effects. At termination of exposure, foliar injury was estimated and the plants were prepared for sodium and chloride analysis. Microscopic anatomical examinations of leaf sections were also conducted. The toxicity of the salt aerosol to three stages of growth of the bush bean plant was thereby determined, as well as approximation of the threshold aerosol concentration that would produce visible injury.

OBJECTIVES

Phase I

To acquire pre-activation baseline salt concentration data and to provide for the assessment of incremental impact, if any, of salt aerosol loading from test cooling devices on selected indigenous vegetation, soil and fresh water in proximity of the Turkey Point Site.

Phase II

To identify and characterize the influence of sea salt aerosol drift on introduced cultivar plants sited at varying distances from the test cooling devices.

Phase III

To define salt aerosol tolerance levels for bush bean by examining full term growth effects on plants experimentally exposed to aerosol concentrations representative of those from the Turkey Point test cooling tower/PSM system.

SECTION V

PHASE I, INCREMENTAL IMPACT ANALYSIS OF SALT AEROSOL LOADING ON INDIGENOUS ENVIRONMENT

DESIGN AND PROCEDURES

Indigenous Vegetation

To determine the extent of variations in the concentration of sea salt aerosol deposition, baseline data were obtained prior to activation of the new cooling devices. Phase I included sampling and salt analysis of Mangrove leaves (*Avicinna marina*). This indigenous plant species was sampled from Sites 2, 3, 4, and 7 (Figure 7). The Mangrove leaves were collected routinely at weekly intervals beginning three months prior to, during, and two months following operation at the test cooling devices. Harvested leaves were all approximately the same age and size, 2.5 cm x 10 cm. The samples were oven dried and shipped to Corvallis, Oregon for sodium determination by flame spectrophotometry (37).

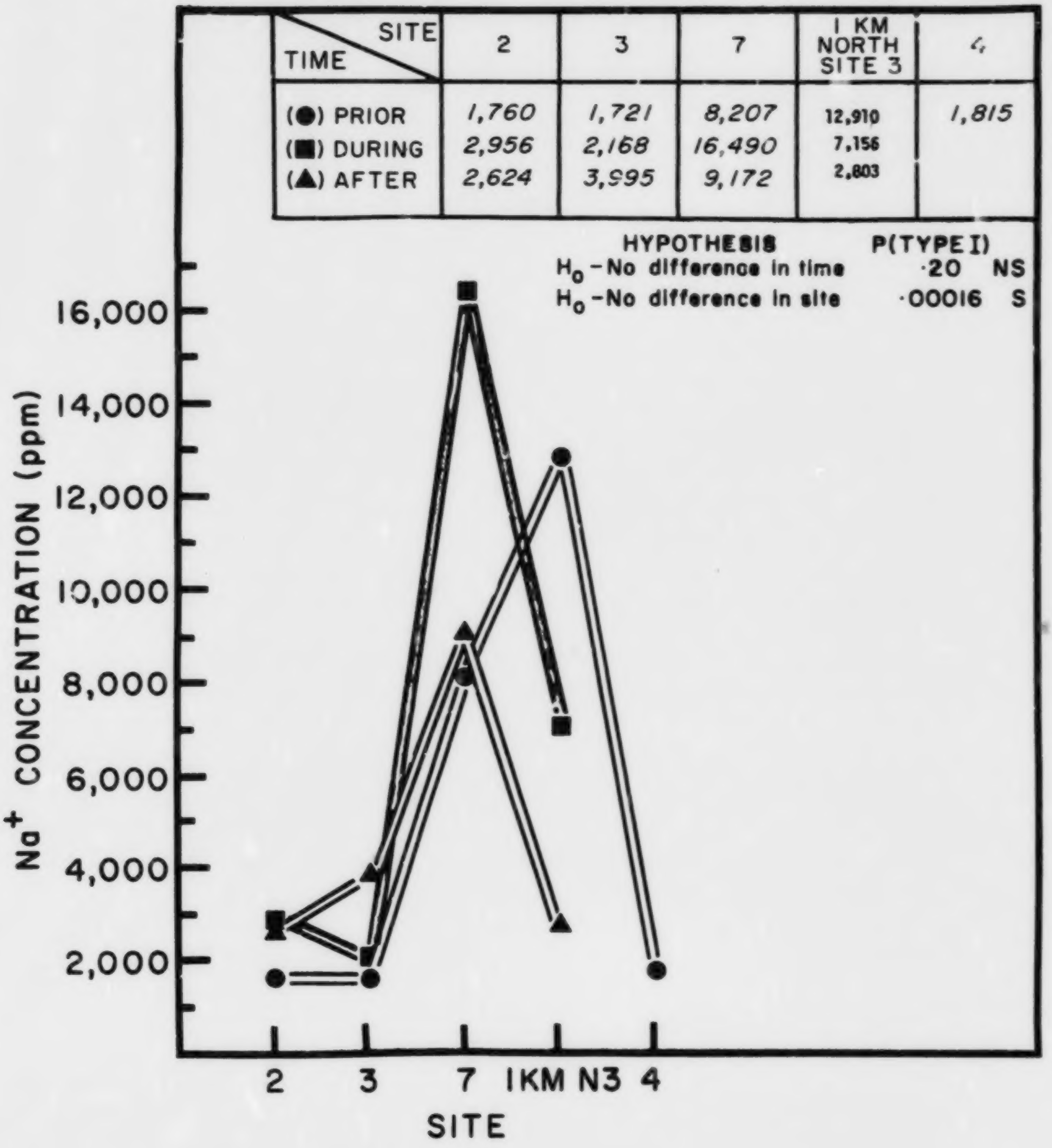
Soil and Fresh Water

Native soil and water samples were collected near the Turkey Point installation. The samples were gathered every three weeks for four months prior to, during, and four months after activation of the cooling devices. The four soil collection sites were located at Site 4 and three sites at .8 km increments due north of Site 4. The water samples were collected from Site 2 and three locations at .8 km increments north of Site 2. Native soil samples were analyzed for nitrogen, phosphate, and potassium fertility as well as chloride. The local fresh water samples were analyzed for chloride concentration and pH. The Florida Cooperative Extension Service at Homestead, Florida performed the chemical analysis of the local soil and fresh water (38, 39, 40).

RESULTS AND DISCUSSION

Indigenous Vegetation

The salt concentration, as measured by sodium flame spectrophotometric analysis, of Mangrove leaves (*Avicinna marina*) was examined to determine the relationship between natural salt levels and possible elevated salt concentration in native vegetation attributed to the test cooling devices. The leaf analysis data are presented in Figure 8 and Table 1. Average sodium concentration increased during and following cooling tower/spray module operation. However, variance analysis showed no significant differences among the three sampling periods. The leaf



SITE / TIME	2	3	7	1 KM NORTH SITE 3	4
(●) PRIOR	1,760	1,721	8,207	12,910	1,815
(■) DURING	2,956	2,168	16,490	7,156	
(▲) AFTER	2,624	3,995	9,172	2,803	

HYPOTHESIS	P(TYPE I)	
H_0 – No difference in time	·20	NS
H_0 – No difference in site	·00016	S

Figure 8.

Na$^+$ concentration (ppm) of Mangrove leaves (*Avicinnia marina*) collected in the proximity of the Turkey Point Cooling Tower three months prior, during and two months after test activation

TABLE 1. SODIUM (PPM) IN MANGROVE LEAVES PRIOR, DURING AND AFTER COOLING TOWER/SPRAY MODULE ACTIVATION

	Prior		During		After	
Site	Range	Average	Range	Average	Range	Average
2	950-4280	1760	1200-4340	2956	1700-4000	2624
3	316-10180	1721	270-9910	2168	1420-4060	3995
1 km North Site 3	3480-25500	12900	1790-12050	7156	2160-3620	2803
7	1550-17000	8207	1990-48700	16490	2010-27100	9172
4	1120-2980	1815				

Sodium levels did not change significantly ($P>0.05$) in Mangrove leaves with respect to time. However, sodium levels did vary significantly ($P<0.01$) with respect to location. $\bar{n} = 7$, for each site period.

sodium concentration did not correlate with cooling device aerosol exposure. Assuming relatively constant background concentrations of salt, this lack of correlation implies that any incremental salt aerosol loading from the operation of cooling tower/spray module complex was minor compared to other natural salt loading factors in the sampled mangrove leaves.

The statistical analysis did indicate a significant difference in leaf sodium concentration among sampling sites during each sampling period (Table 1). Because the sodium contribution of the cooling device was insignificant, this intersite difference reflects the natural background distribution of salt loading among the sites. For example, the average leaf sodium contribution was higher for the remote Site 7 than for other sites closer to the cooling devices. Wind exposure might have been relatively higher at Site 7 giving the site a comparatively higher saline collection rate from equivalent aerosol concentrations. However, the magnitude of the difference suggests soil salinity differences at root levels as the most probably differentiating parameter among the sites. Supporting this hypothesis is the fact that Site 7 was located in an area closely surrounded by salt water interceptor and cooling canals. Whatever the background causes of intersite differences, no significant intrasite differences were detected over the full term of Phase I.

Soil and Fresh Water

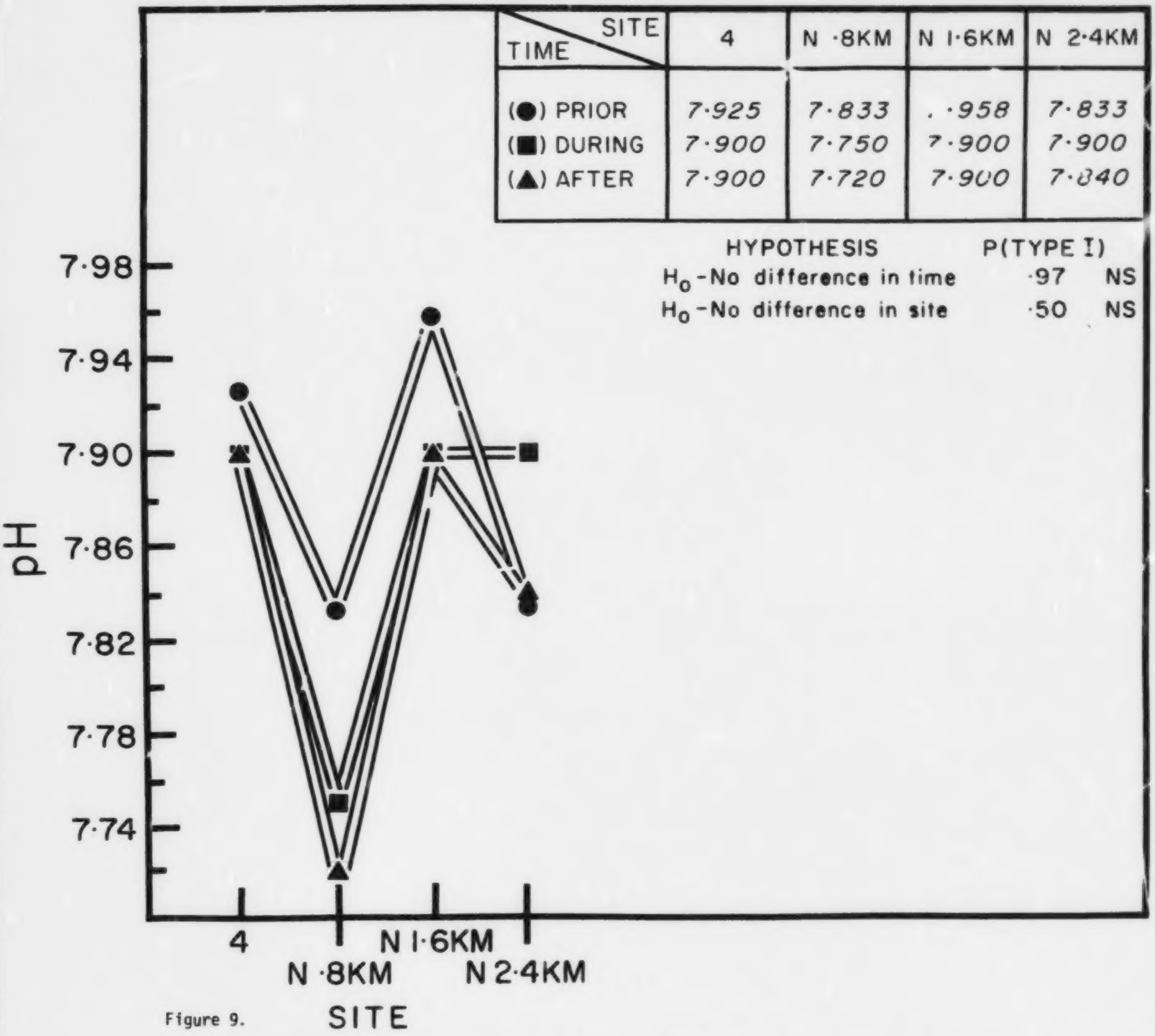
The native soil samples were analyzed for phosphate, calcium, chloride and pH. Comparative Intersite comparisons of trend of pH

(Figure 9 and Table 2) generally remained the same throughout the ten months study period. The nitrate (Figure 10, Table 2) determination showed no significant variation with time or sampling site.

With varying degrees of significance, the chloride, calcium and phosphorus assays showed roughly the same intersite trend (Figures 10 and 11, Table 3) with respect to site concentrations and time variation. Concentration followed the same overall intersite pattern throughout the sampling period, increasing for all three elements. Intrasite soil concentrations markedly increased after the mid-January to mid-March tower test. Any statistical relationship between tower operation and an intersite concentration change of such magnitude and uniformity probably is spurious, considering the very low phosphorus and calcium content in sea salt aerosol, the sample site remoteness from the cooling tower, and the short duration of the actual tower test.

The uniform overall intrasite increase reflects a normal seasonal variation in mineral leaching near the sample sites. This elevated concentration of salts in natural calcarious soil coincides with soil moisture which also increased as the minimal winter rainfall yielded to heavier spring and summer rains.

Both water pH and chloride concentration (Figure 12 and Table 4) increased slightly, but these increases were statistically insignificant with respect to sampling period and collection site.



TIME \ SITE	4	N ·8KM	N 1·6KM	N 2·4KM
(●) PRIOR	7·925	7·833	. ·958	7·833
(■) DURING	7·900	7·750	7·900	7·900
(▲) AFTER	7·900	7·720	7·900	7·840

HYPOTHESIS	P(TYPE I)	
H_0-No difference in time	·97	NS
H_0-No difference in site	·50	NS

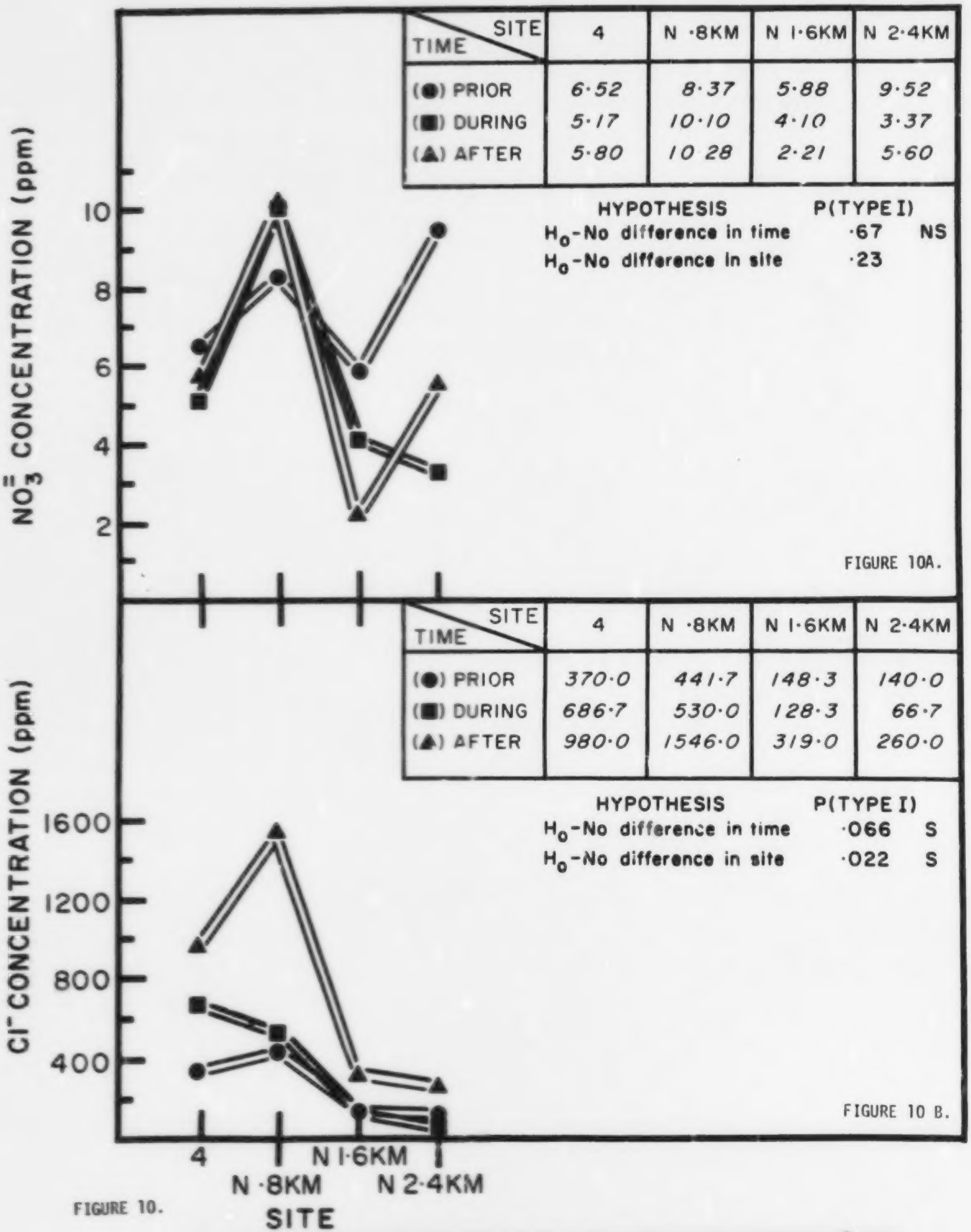
Figure 9.

pH of native soil samples collected at Site 4, ·8KM North, 1·6KM North, and 2·4KM North of Site 4 prior, during and after Tower activation

TABLE 2. SOIL pH AND NITRATE MEASUREMENTS AT TURKEY POINT SITES

	Prior		During		After	
Site/pH	Range	Average	Range	Average	Range	Average
4	7.8-8.2	7.900	7.9-7.9	7.900	7.8-8.0	7.900
N.8 Km	7.5-8.2	7.833	7.6-7.95	7.750	7.5-7.8	7.720
N1.6 Km	7.8-8.25	7.958	7.8-8.1	7.900	7.7-8.0	7.840
N2.4 Km	7.7-8.3	7.833	7.8-8.0	7.900	7.7-8.0	7.840
Site/NO_3 ppm						
4	.12-11	6.52	.5-10	5.17	1 -11	5.80
N.8 Km	.2-15	8.37	.3-18	10.10	.4-15	10.28
N1.6 Km	.3-9	5.88	.3-8	4.10	.1-5	2.21
N2.4 Km	.1-16	9.52	.1-10	3.37	2-9	5.60

pH or nitrate levels did not change significantly ($P>0.05$) in soil collected during three time periods (i.e., before, during or after tower operation). $\bar{n} = 5$, for each site period.



TIME \ SITE	4	N ·8KM	N 1·6KM	N 2·4KM
(●) PRIOR	6·52	8·37	5·88	9·52
(■) DURING	5·17	10·10	4·10	3·37
(▲) AFTER	5·80	10·28	2·21	5·60

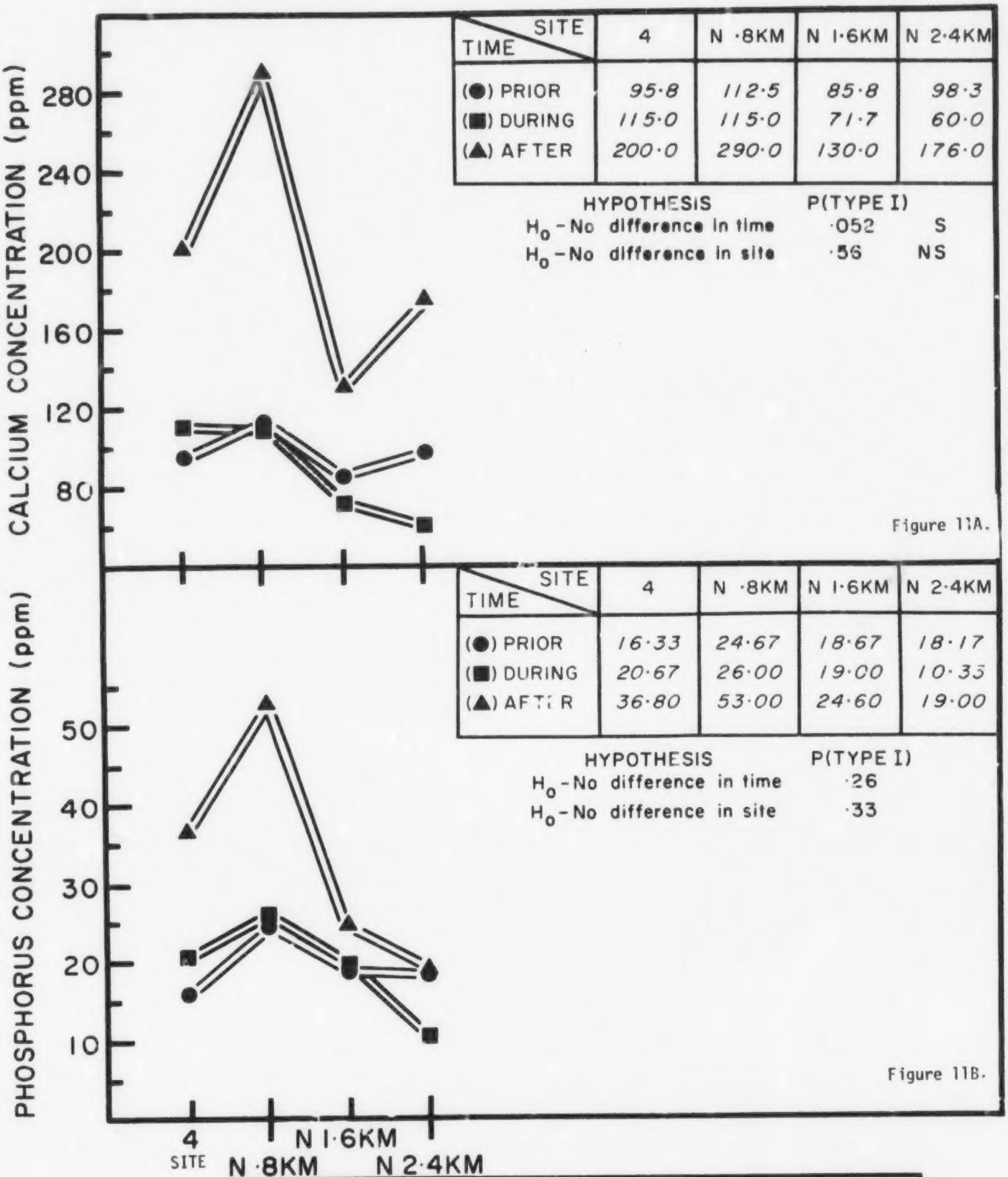
HYPOTHESIS	P(TYPE I)	
H_0-No difference in time	·67	NS
H_0-No difference in site	·23	

TIME \ SITE	4	N ·8KM	N 1·6KM	N 2·4KM
(●) PRIOR	370·0	441·7	148·3	140·0
(■) DURING	686·7	530·0	128·3	66·7
(▲) AFTER	980·0	1546·0	319·0	260·0

HYPOTHESIS	P(TYPE I)	
H_0-No difference in time	·066	S
H_0-No difference in site	·022	S

FIGURE 10.

$NO_3^=$ and Cl^- concentration (ppm) of native soil samples collected at Site 4, ·8KM North, 1·6KM North, and 2·4KM North of Site 4 prior, during and after Tower activation



SITE / TIME	4	N ·8KM	N 1·6KM	N 2·4KM
(●) PRIOR	95·8	112·5	85·8	98·3
(■) DURING	115·0	115·0	71·7	60·0
(▲) AFTER	200·0	290·0	130·0	176·0

HYPOTHESIS	P(TYPE I)	
H_0 - No difference in time	·052	S
H_0 - No difference in site	·56	NS

Figure 11A.

SITE / TIME	4	N ·8KM	N 1·6KM	N 2·4KM
(●) PRIOR	16·33	24·67	18·67	18·17
(■) DURING	20·67	26·00	19·00	10·33
(▲) AFTER	36·80	53·00	24·60	19·00

HYPOTHESIS	P(TYPE I)
H_0 - No difference in time	·26
H_0 - No difference in site	·33

Figure 11B.

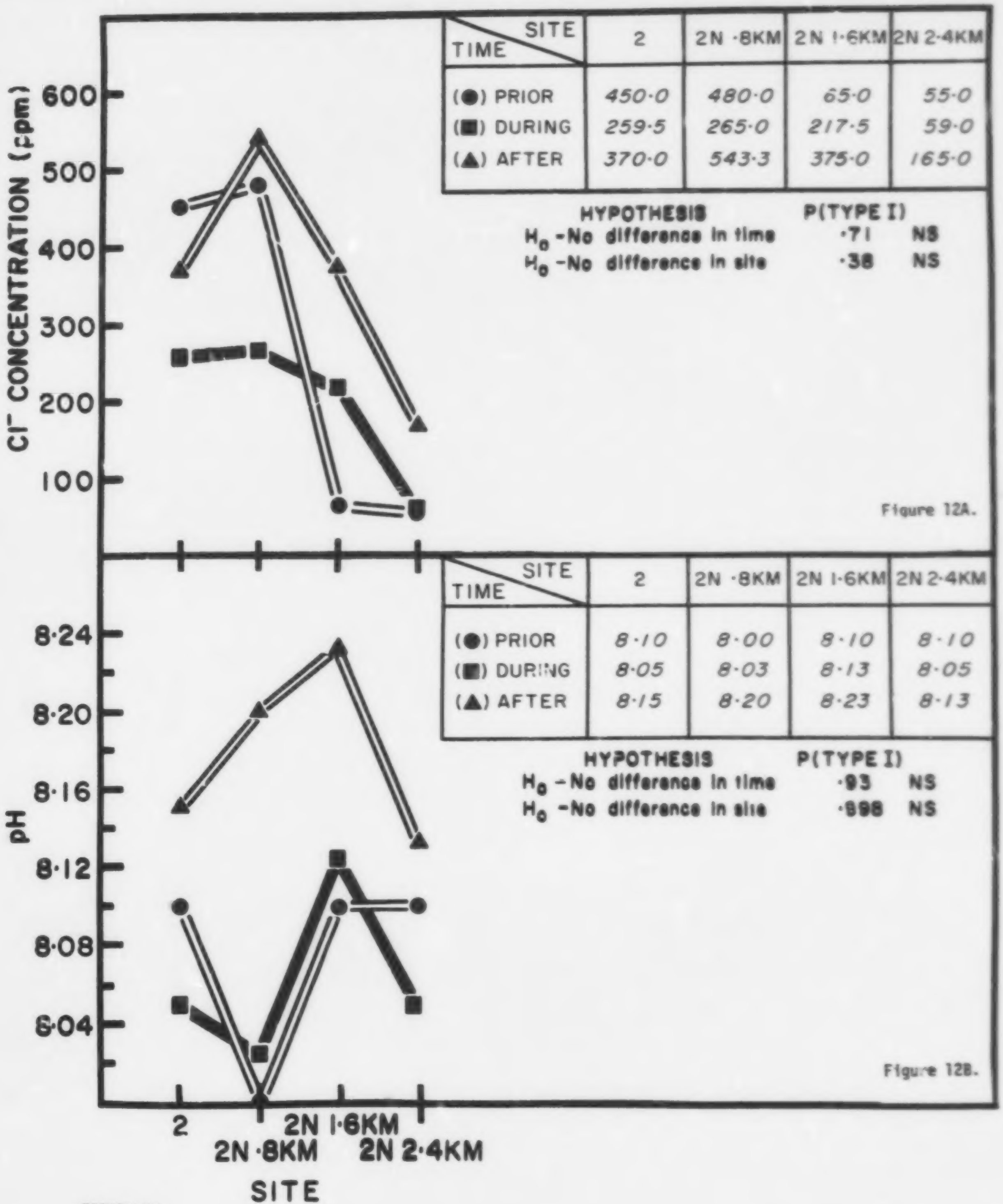
FIGURE 11.

Calcium and phosphorus concentration (ppm) of native soil samples collected at Site 4, ·8KM North, 1·6KM North, and 2·4KM North of Site 4 prior, during and after Tower activation

TABLE 3. SOIL CHLORIDE, CALCIUM AND PHOSPHORUS MEASUREMENTS AT TURKEY POINT SITES

	Prior		During		After	
Site	Range	Average	Range	Average	Range	Average
Chloride ppm						
4	20-700	370	210-1400	686.7	500-1150	980.0
N.8 Km	20-800	441.7	490-600	530.0	505-4500	1546.0
N1.6 Km	20-290	148.3	50-250	128.3	65-700	319.0
N2.4 Km	20-250	140.0	50-80	66.7	100-490	260.0
Calcium ppm						
4	50-150	95.8	210-1400	115.0	500-1150	290.0
N.8 Km	50-200	112.5	70-150	115.0	100-750	290.0
N1.6 Km	40-125	85.8	40-100	71.7	75-200	130.0
N2.4 Km	40-150	98.3	40-100	60.0	75-400	176.0
Phosphorous ppm						
4	2-25	16.33	4-40	20.67	25-79	36.80
N.8 Km	2-65	24.67	3-40	26.00	25-120	53.00
N1.6 Km	2-35	18.67	2-30	19.00	16-35	24.60
N2.4 Km	2-30	18.17	2-25	10.33	10-30	19.00

Chloride and phosphorous levels in soil collected during the three time periods (i.e., before, during or after tower operation) did not change increase significantly. $\bar{n} = 5$, for each site period.



TIME \ SITE	2	2N ·8KM	2N 1·6KM	2N 2·4KM
(●) PRIOR	450·0	480·0	65·0	55·0
(■) DURING	259·5	265·0	217·5	59·0
(▲) AFTER	370·0	543·3	375·0	165·0

HYPOTHESIS	P(TYPE I)	
H_0 - No difference in time	·71	NS
H_0 - No difference in site	·38	NS

TIME \ SITE	2	2N ·8KM	2N 1·6KM	2N 2·4KM
(●) PRIOR	8·10	8·00	8·10	8·10
(■) DURING	8·05	8·03	8·13	8·05
(▲) AFTER	8·15	8·20	8·23	8·13

HYPOTHESIS	P(TYPE I)	
H_0 - No difference in time	·93	NS
H_0 - No difference in site	·898	NS

FIGURE 12.

Cl⁻ concentration and pH of water samples collected at Site 2, ·8 KM North, 1·6 KM North, and 2·4 KM North of Site 4 prior, during and after Tower activation

TABLE 4. WATER pH AND CHLORIDE MEASUREMENTS AT TURKEY POINT SITE

	Prior		During		After	
Site/pH	Range	Average	Range	Average	Range	Average
2	8.10-8.10	8.10	7.9-8.2	8.05	7.90-8.40	8.15
2N.8 Km	8.00-8.00	8.00	7.80-8.25	8.03	8.20-8.20	8.20
2N1.6 Km	8.10-8.10	8.10	8.00-8.25	8.13	8.20-8.30	8.23
2N2.4 Km	8.10-8.10	8.10	7.90-8.2	8.05	7.90-8.30	8.13
Chloride	ppm					
2	450-450	450	219-300	259.5	260-440	370.0
2N.8 Km	480-480	480	230-300	265.0	270-1050	543.3
2N1.6 Km	65-65	65	60-375	217.5	160-500	375.0
2N2.4 Km	55-55	55	48-70	59	140-210	165.0

Water pH or chloride levels did not change significantly ($P > 0.05$) with respect to sampling period or collection site. $\bar{n} = 3$, for each site period.

SECTION VI

PHASE II - INCREMENTAL IMPACT ANALYSIS OF SALT AEROSOL LOADING ON INTRODUCED VEGETATION

DESIGN AND PROCEDURES

Cooling Device Operation

Phase II of the study involved the introduction and exposure of two representative food crops at the Turkey Point test site. Work was scheduled for the eight week period from January 15, 1974, to March 15, 1974, (Julian dates 15-74). During this test, the cooling tower and powered spray modules (PSM) were operated alternately for varying periods of time (Table 5). The cooling devices normally did not operate simultaneously except for one brief three hour period in January. Mechanical difficulties prevented achieving the preplanned schedule of operation. The cooling tower operated about 40% and the PSM only about 6% of the time (Table 6), leaving approximately 54% of the total available time free of any added salt aerosol loading.

Airborne Particle Sampler (APS) Network

APS equipment and support systems were placed at preselected sites to monitor salt aerosol concentrations. Samples were taken daily for five days each week throughout the test period. In addition, dew-point temperature, ambient air temperature, wind speed and wind direction were recorded at the initiation and termination of all APS sampling runs by Environmental Systems Corporation (ESC) in accordance with contract schedule (41). Hourly weather observations were also rountinely recorded at the main reactor site by Florida Power and Light.

Baseline ambient salt aerosol sampling prior to cooling device testing was conducted between late August, 1973 and mid-January, 1974. The six site, sampling network extended from 1,665 meters east to 770 meters west along a central transect through the cooling site. Four supplemental APS sites were added to the network when plants were introduced in Mid-January, 1974.

Vegetation Site Selection

The high seasonal frequency of salt-laden, easterly winds in contrast to comparatively low ambient salt aerosol concentrations of noneasterly winds served as the basis for quantatively describing the relative contribution of natural and anthropogenic sources of salt loading. The principal string of sites for assaying crop effects was located along the same line as the preliminary APS transect. Marshy

TABLE 5. COOLING TOWER AND POWERED SPRAY MODULES (PSM) OPERATION LOG

Date Julian	Tower	PSM
Jan. 15	0800-1000	1100-1600, 1700-1800
16	0800-1000	
17	0800-1000	
18	0800-1000	
19	0800-1000	
20	0800-1000	
21	0800-1400	
22	1300-1630	
23	1030-1500	
24		
25		
26	1200-1730	
27		
28		
29		1000-1800
30		0900-1900
31		0830-1900
Feb. 1 (32)		0830-1910
2 (33)		0900-1330
3 (34)		
4 (35)		
5 (36)		
6 (37)		
7 (38)		Start 24 hour operation
to		1130
16 (47)		Off 1000 (transformer out)
18 (49)		1000-1900
19 (50)	1045-1730	
20 (51)	0945-1915	
21 (52)	Start 24 hour operation	
to	0930	
Mar. 15 (74)		

TABLE 6. SCHEDULE OF COOLING TOWER AND POWERED SPRAY MODULES OPERATION

	% Cooling Tower Operational	% Spray Module Operational
Jan. 15-30	8.2	8.9
Feb. 1-28	31.0	7.2
March 1-15	100.0	0
Jan. 15-March 15 (full-time)	42.0	5.8

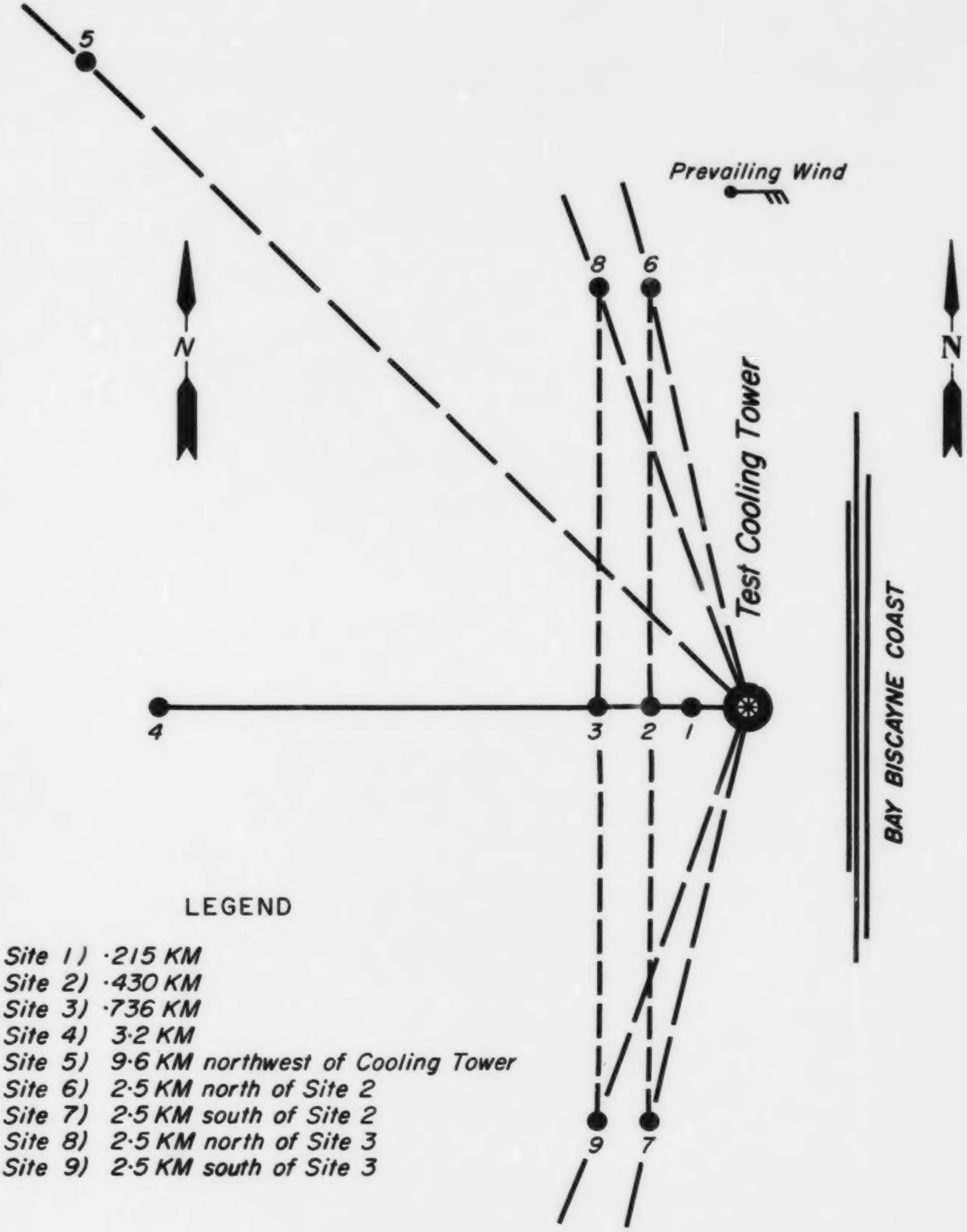
terrain and cooling canals complicated access and placement of sites north and south of the central east-west tower transect. However, acceptable locations were secured 2.5 km either side of this central transect. This configuration was designed to provide a means of separating the cooling tower/PSM contribution from the natural background aerosol drift off Biscayne Bay.

The principal string of plant exposure sites were on the central transect. These sites were located 215, 430, 736, 3200 meters west of the cooling devices and numbered 1 through 4, respectively (Figure 13). Two other sets on sites ran parallel at a distance of 2.5 km north and south of the central transect. The two displaced parallels each had two sites. These locations were numbered as Sites 6 and 8 and Sites 7 and 9, respectively. Site 5 was remote at a location 9.6 km northwest of the Turkey Point cooling tower.

Within the first month of operation, flooding, accessing and security problems necessitated abandonment of four sites. Sites 1, 2, 3, 7, and 9 remained operational for the entire eight weeks of Phase II.

Introduced Vegetation

Bush bean (*Phaseolus vulgaris L.* var. Contender) and sweet corn (*Zea mays L.* var. Golden Hybrid) were positioned at the above selected sites. The introduced plants had been grown from seeds planted in six inch plastic pots filled with Jiffy Mix Plus. The pots were maintained in an outdoor frame house through the first two weeks of plant growth. Fifteen day old plants of each species were placed at each site in sets of 15 at one week intervals throughout the eight week test period. Plants were harvested at weekly intervals after one, two, and three weeks of exposure. At each of Sites 3 and 7, an additional 12


5
Prevailing Wind
8
6
N
N
Test Cooling Tower
BAY BISCAYNE COAST
4
3
2
1
9
7

LEGEND

Site 1) ·215 KM
Site 2) ·430 KM
Site 3) ·736 KM
Site 4) 3·2 KM
Site 5) 9·6 KM northwest of Cooling Tower
Site 6) 2·5 KM north of Site 2
Site 7) 2·5 KM south of Site 2
Site 8) 2·5 KM north of Site 3
Site 9) 2·5 KM south of Site 3

Figure 13. Vegetation Site Location

bush bean and 12 sweet corn plants were grown in large tubs through the entire test period. The harvested plants were oven dried, then shipped to Corvallis for elemental sodium and chloride analysis (37).

Introduced Soil

Five months prior to activation of the cooling tower, unseeded six-inch planting pots containing the same soil mix as the exposed bean and corn pots were introduced at Sites 2 and 3. Pot samples were drawn at monthly intervals until the field test period terminated in March. The soil samples were placed in labeled plastic bags and sent to Corvallis where the Oregon State University Soil Testing Laboratory determined the pH and sodium concentrations of the introduced soil (42). Examination of variations in the pH and sodium concentrations of the introduced soil showed no statistically significant differences with respect to sampling date or location (Table 7).

TABLE 7. INTRODUCED SOIL pH AND SODIUM MEASUREMENTS AT TURKEY POINT SITES

	Prior		During	
Site/pH	Range	Average	Range	Average
2	6.6-7.5	7.15	7.5-7.9	7.70
3	7.0-7.3	7.13	8.0-8.0	8.00
Sodium ppm				
2	16.0-91.96	39.64	29.89-45.99	37.94
3	4.6-16.0	8.40	22.90-22.90	22.90

Introduced soil pH and Sodium levels did not change significantly in soil collected during the two time periods (i.e., before and during tower operation). $\bar{n}$ = 3, for each site period.

RESULTS AND DISCUSSION

Combined Effects of Cooling Tower and Powered Spray Modules (PSM)

Chemical analysis of bean and corn aerial tissue showed quite pronounced differences in salt accumulation after three weeks of exposure. The overall average salt concentrations were highest in plants exposed closest to the cooling tower site, roughly decreasing exponentially with increased distance from the source (Figure 14). Plants exposed at Site 1 exhibited unusually high salt accumulations, ($P<0.01$, i.e. the probability (P) of rejecting the null hypothesis, "no difference", commits a Type 1 error is less than the 99% level of significance). Site 1 plants showed salt tissue concentrations nearly an order of magnitude greater than those of the more distant Site 3, i.e., 3,560 vs 480 ppm sodium in bean; 3,800 vs 382 ppm sodium in corn. Intersite chloride accumulation levels reflected much the same trend as sodium with significantly higher ($P<0.05$) chloride levels at Site 1.

The lack of additional sites complicated the unequivocal establishment of the extinction point for acute salt aerosol cooling device impact. However, APS data gathered during the test period showed that airborne salt concentrations at Site 3 were comparable to those of more distance sites on other transects. The plant salt concentrations from Site 9, due south of Site 3, also were comparable to those encountered at Site 3. Site 3, therefore, was judged to conservatively approximate the minimum background salt concentration level of the central transect.

The plant salt concentrations measured at Site 2, were not significantly higher than those at Site 3 during the period of test (Figure 15). However, this does not preclude the possibility that the salt concentrations may have been statistically different at these sites if the plants had been exposed for longer periods.

Considering all the data gathered in Phase II, only Site 1 consistently reflected any real increase in plant salt accumulation as a possible result of incremental aerosol loading from test cooling devices. Plants at Site 1 also exhibited symptoms of salt toxicity (Figure 16, 17) whereas plants at other sites did not. Based on these observations it is concluded that the distance to Site 1 (215 m) approximately delineates the radial zone where cooling device aerosol had a possible detrimental impact on the introduced bean plants under the environmental conditions that existed during the eight week test period of Phase II.

Quantitative delineation of the separate sea salt aerosol contributions of the cooling tower and spray modules to the observed plant salt accumulations have proven to be elusive. Environmental variability appears to obscure any definitive correlation among tri-weekly exposure sets of plants. However, plants of the same tri-weekly

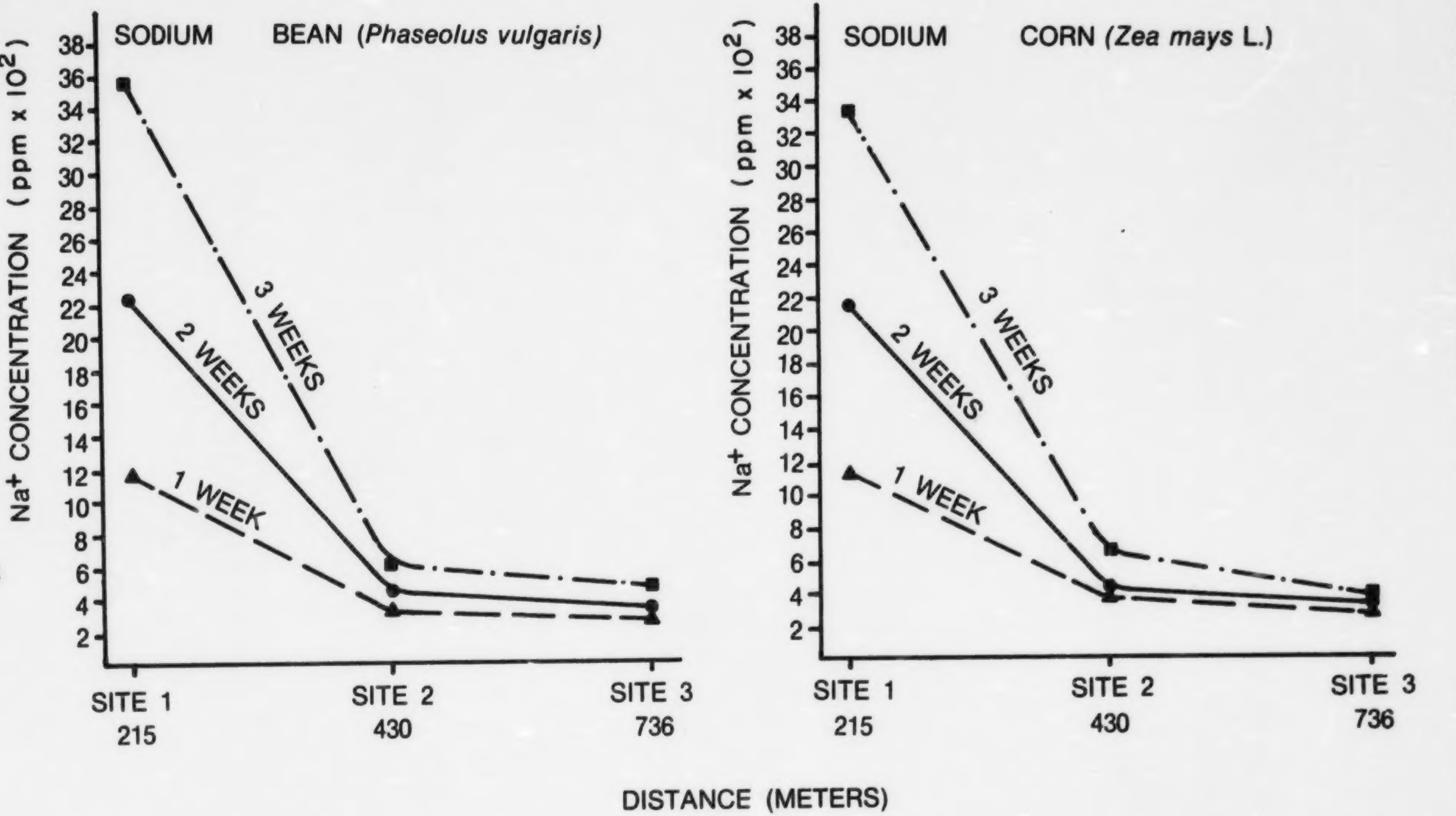


Figure 14. Mean sodium concentration (ppm dry tissue) for all bean and corn plants following one, two and three weeks exposure at Sites 1, 2 and 3 on the western radical transect of the Turkey Point cooling tower illustrating increased proximity effect with longer exposure periods.

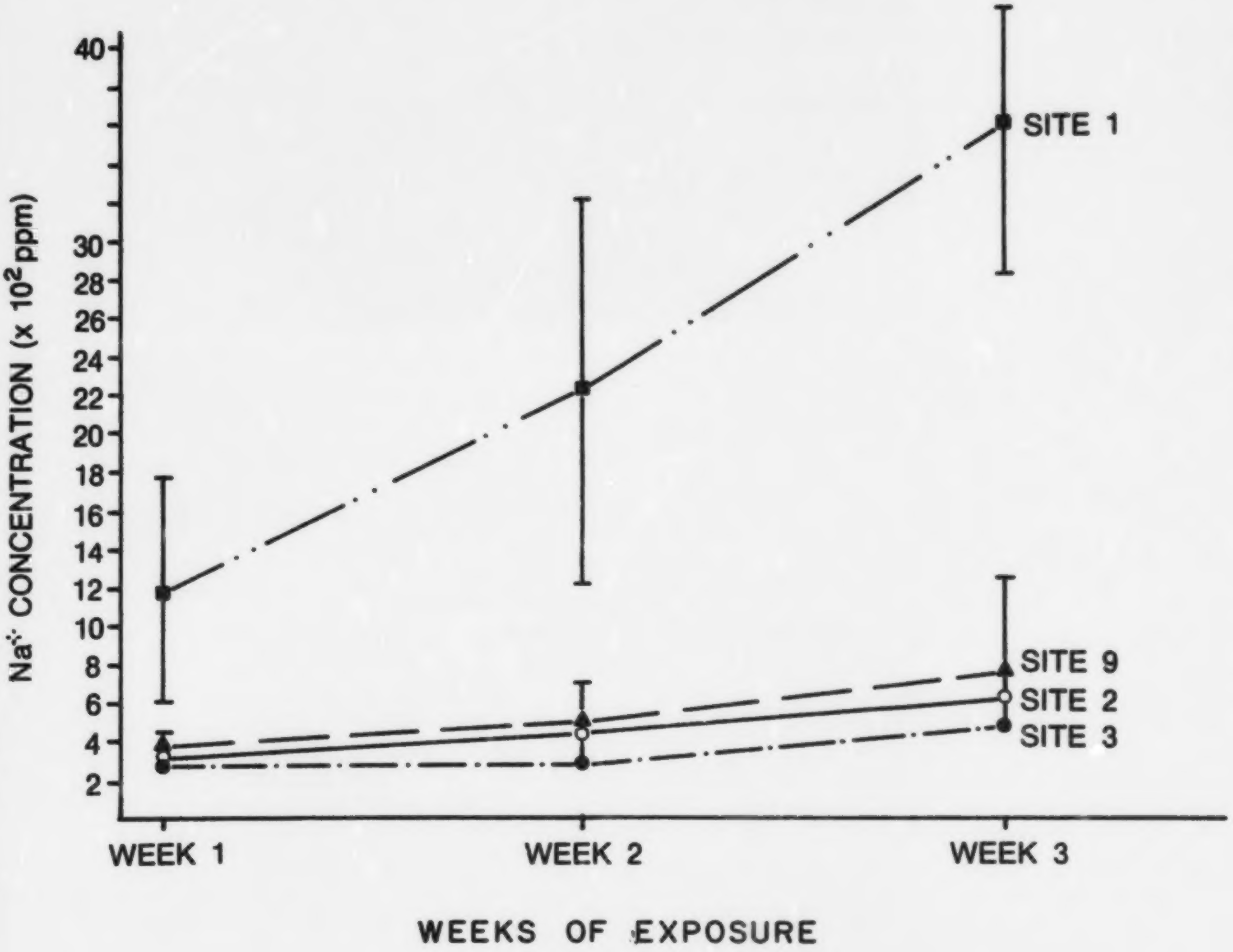


Figure 15. Mean sodium concentration for all bean plants at Sites 1, 2, 3, and 9 following one, two and three weeks ambient exposure. Shows significantly higher concentrations at Site 1 in relation to the more distant Site 3 for all weeks. (Site 1, .215 km; Site 2, .430 km; Site 3, .736 km; Site 9, 2.6 km). Vertical bars denote 95% confidence limits for mean Site 1 and 3 values.

Figure 16. Crinkling and yellowing on bush bean exposed at site 1 at Turkey Point.

Figure 17. Marginal and spots of tissue injury on bush bean exposed at site 1 at Turkey Point.

exposure set can be meaningfully compared since they shared common environmental conditions and differed only in drift exposure. The number of meaningful drift exposure periods were reduced when maintenance difficulties hampered continuous operation of the cooling devices early in the test period. Furthermore, the frequency of easterly wind during the test period was far less than climatologically expected. The combination of unpredictable winds and intermittent cooling device operations precluded the consistent determination of incremental loading from the cooling tower or powered spray modules. During most of the test period additional loading was so brief or comparatively minor that it apparently remained obscured in the natural background variation of salt aerosol concentrations.

Conditions, however, were favorable for the exposure of the plants to drift on the central transect during the latter portion of the test period. After February 20, 1974 (Julian date 51), the cooling tower operated 24 hours a day, while the winds generally blew from a more typical easterly direction. These conditions directed the cooling tower drift over the central transect for comparatively long periods of time. The plants closest to the tower appeared to directly reflect an increased salt aerosol loading during that period.

Cooling Tower Drift Contribution to Plant Salt Accumulation

Sodium and chloride concentrations of the plant tissue sampled were plotted for each site on the central transect for periods of critical wind (i.e., easterly winds coincident with tower operation). These plots show that plant sodium and chloride accumulations at Site 1 were directly dependent on the amount of time the plants were exposed to cooling tower and east wind drift during the February 20 to March 15, 1974 period (Julian dates 51-74, Figures 18 and 19). In addition to higher salt accumulations, bean plants at Site 1 were the only plants to exhibit any salt toxicity symptoms (marginal leaf chlorosis and blade discoloration) during this three week exposure period (Julian dates 51-74).

The sodium and chloride accumulation levels from the aboveground portions of the bean and corn plants from Site 1 were markedly higher ($P<0.01$) than the salt accumulations of plants from Sites 2 and 3 after 180 cumulative hours of tower drift exposure. The tri-weekly averages of APS salt aerosol measurements, from ESC monitoring sites, showed higher mean values at Site 1 during the period with predominantly easterly component winds (Figure 20). The salt concentrations from Site 3 bean plants demonstrated comparatively little change with time and probably approximated the minimum ambient (natural) levels for the central transect. Site 2 bean plants generally had higher terminal salt accumulations than Site 3, but Site 2 apparently was so close to ambient levels that accumulations there did not consistently differ significantly from Site 3. Salt accumulation with corn plants reflected the same trend as the bush beans, with higher salt concentrations near the cooling tower.

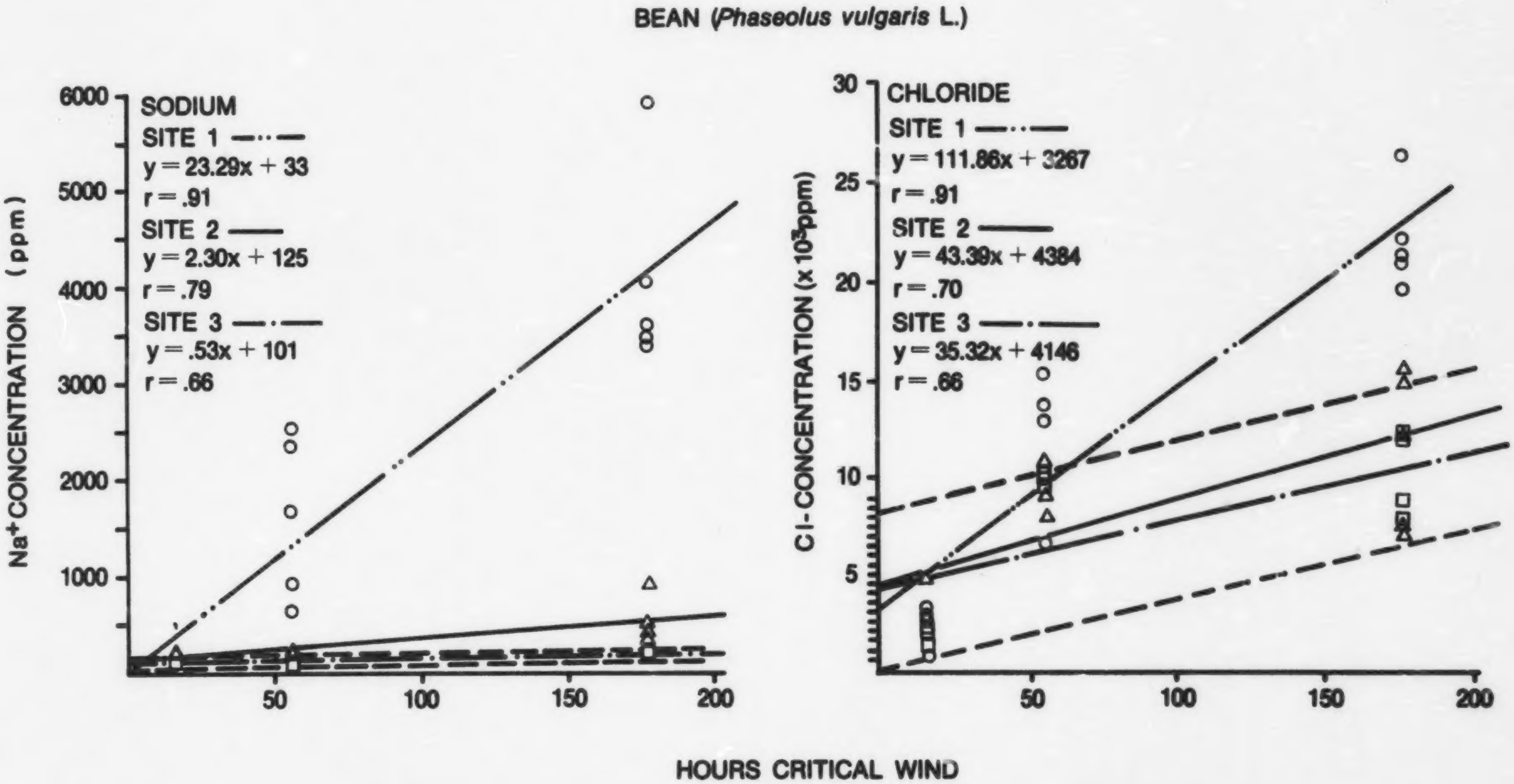


Figure 18. Plot and least squares linear regression of western transect bean salt component (ppm dry tissue) against critical wind exposure (hours) at Turkey Point, Florida for time period spanning Julian dates 52-74. Critical wind is defined as wind which directed cooling device drift toward plant site location. Parallel dashed line represents centroid-biased 95% confidence limits for Site 3 regression (○ Site 1, △ Site 2, □ Site 3.)

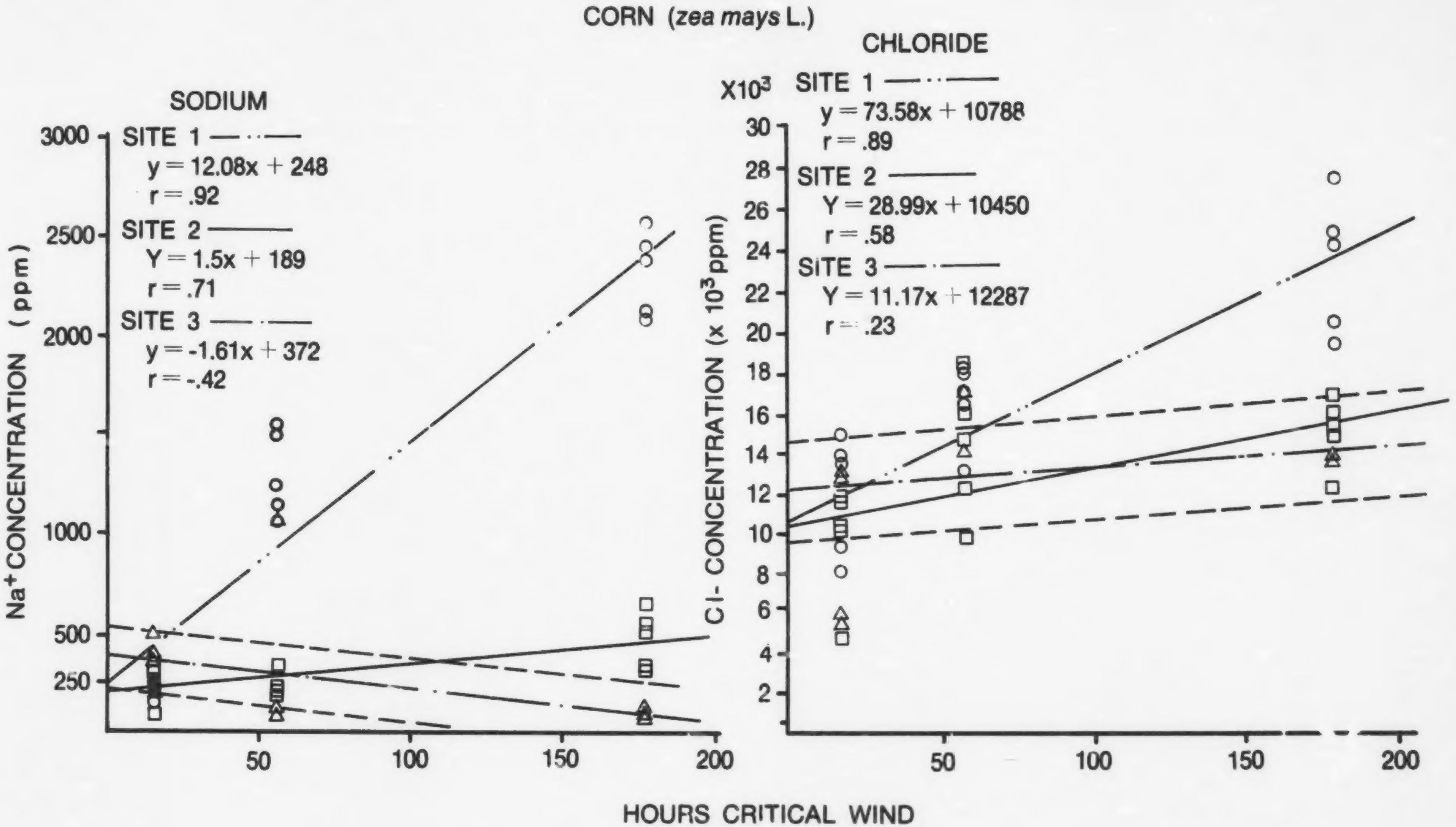


Figure 19. Plot and least squares linear regression of western transect corn salt components (ppm dry tissue) against critical wind exposure (hours) at Turkey Point, Florida for time period spanning Julian dates 52-74, 1974. Dashed line represents centroid-biased 95% confidence interval for site 3 regression line. (o site 1, □ site 2, Δ site 3.)

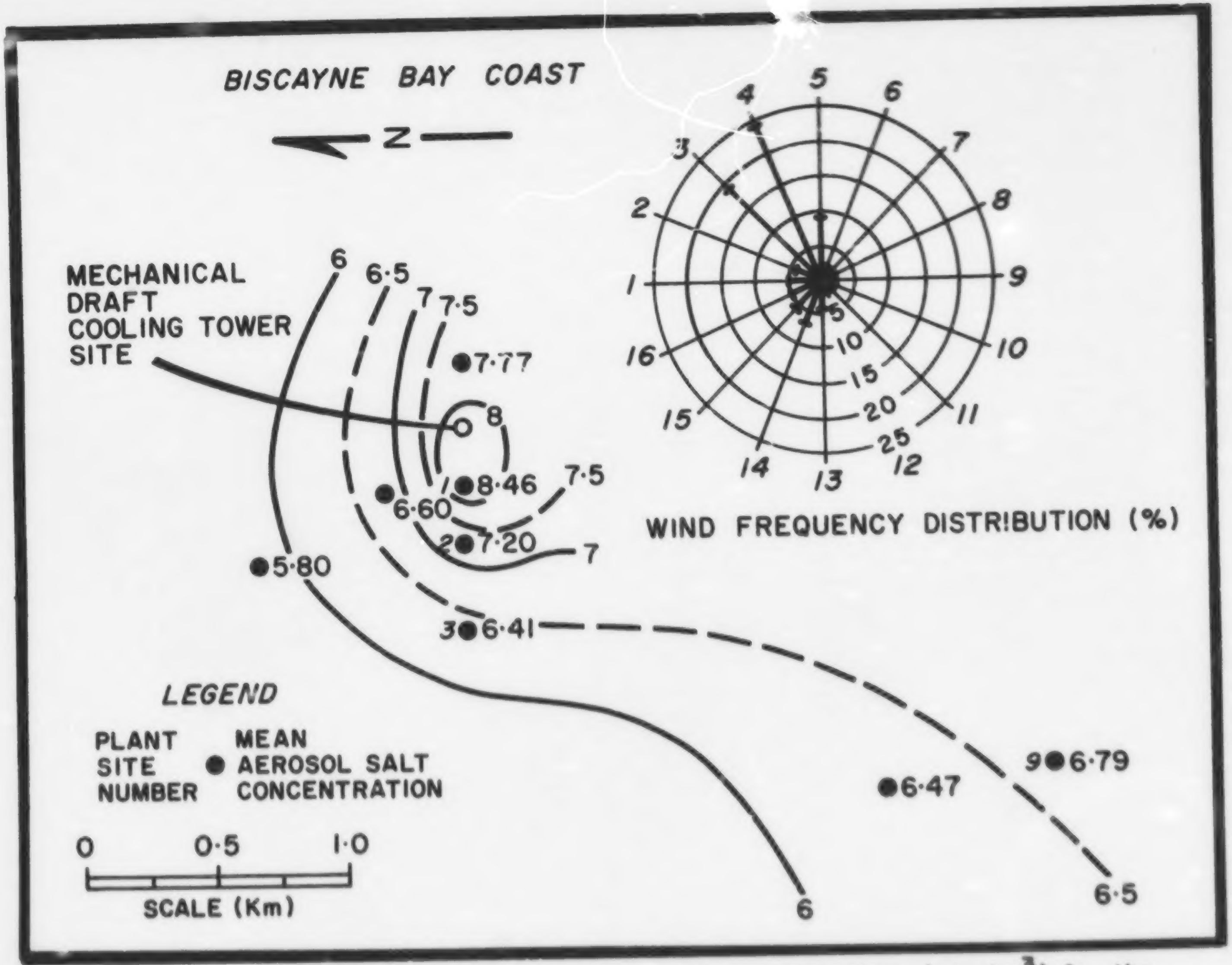

BISCAYNE BAY COAST
N
MECHANICAL DRAFT COOLING TOWER SITE
6
6·5
7
7·5
8
●7·77
1●8·46
●6·60
2●7·20
●5·80
3●6·41
●6·47
9●6·79
WIND FREQUENCY DISTRIBUTION (%)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
5
10
15
20
25
LEGEND
PLANT SITE NUMBER
● MEAN AEROSOL SALT CONCENTRATION
0
0·5
1·0
SCALE (Km)

Figure 20 Isopleths of mean recorded aerosol salt concentrations ($\mu g/m^3$) for the time period 52-74 '74 (Julian date) as measured by an APS Rotary Impaction Sampler. Windrose winds were recorded at the Florida Light & Power Turkey Point weather observing site and are expressed as percent of all hourly observations for the sample period that the wind was from a particular sector (1-16).

The highest natural aerosol background levels for Sites 1, 2, and 3 occurred with easterly onshore winds (39). Consequently, some correlation between easterly winds and salt accumulations would be expected for the plants on the central transect. However, the Site 1 bean and corn plants salt accumulation correlations ($r=.91$) were significantly higher ($P < 0.05$) than the conservative background (Site 3). This could indicate a sizeable incremental salt loading occurred above ambient levels if this western transect lacked a detectable background gradient. However, statistical analysis of the APS data collected during the demonstration of cooling tower operation indicated cooling tower salt aerosol increment to the ambient (background) salt aerosol levels was less than the measurement accuracy of 3 to 5 $\mu g/m^3$ (43). The exposed cultivar plants registered cumulative and transient salt deposition over the entire thre week period. The cumulative and transient effects could have been minimized or misrepresented by the short period, daytime APS aerosol sampling.

This sampling uncertainty and the inability to use the plant sampling net to assess possible ambient gradient effects does not permit eliminating the cooling tower as an incremental source at Site 1. The apparent proximity effects shown by the plant salt accumulation must be interpreted as indicating that if there was a significant cooling tower increment to the plant salt accumulations, it was restricted to plants at Site 1 and was masked by the ambient gradient.

Powered Spray Modules (PSM) Drift Contribution to Plant Site Accumulation

The relation between the spray module contribution and the observed plant concentrations was as equally obscure as that observed for the cooling tower. This was partially attributed to the failure in adequately segregating the operation periods of the cooling tower and the spray modules. Another factor was the relatively short duration of critical east wind during spray module operations. The highest APS salt aerosol concentrations, 30 and 112 $\mu g/m^3$, were recorded at Site 1 downwind from the operating spray modules (Table 8). As long as these peak aerosol concentrations were not transient anomolies, the spray modules should have had at least as much or more at impact at Site 1 under equivalent conditions as the cooling tower. Unfortunately, such a cooling device impact comparison was precluded because plants of different tri-weekly sets did not even receive equivalent critical wind exposure, much less share other environmental conditions during the eight week test period.

Predictive models indicate that spray modules deposit a much greater drift fraction and reach drift extinction considerably closer to the source than cooling towers with similar cooling water circulation rates. However, because of overlapping cooling device operation and short duration of drift exposure, it was not possible to demonstrate a

TABLE 8. PEAK SALT AEROSOL CONCENTRATIONS OF SITE 1-3 DURING PHASE II (BEAN AND CORN EXPOSURE) AT TURKEY POINT

Site	$\mu g/m^3$	Month & day	Time	Time of spray Module Operation	Time of Cooling Tower Operation	Wind Sector	Rh
1	29.72	2/15	10:28-15:30	24:00-24:00	0	5 - 6	63%
1	14.04	2/20	12:53-16.36	0	9:45-19.15	5 - 6	68%
1	14.72	2/21	9:28-14:32	0	24:00-24:00	6	85%
1	17.43	2/28	11:07-15:25	0	24:00-24:00	4 - 5	60%
2	18.82	2/28	11:46-15;41	0	24:00-24:00	4	61%
3	12.43	2/28	13:18-17:36	0	24:00-24:00	4 - 5	53%
1	112.08	3/31*	13:05-17:05	12:10-17:50	0	6 - 8	59%

*after plant study terminated

separate PSM contribution to the plant salt accumulation during Phase II.

The plants on the central transect had the greatest PSM drift exposure from January 30 to February 20, 1974 (Julian dates 30-51). Figure 21 illustrates the elevated plant sodium level measured at Site 1 compared to other central transect sites for plants sampled during that period. The plant chloride levels reflect the same trend (Table 9). The tri-weekly averages of APS salt aerosol measurements also showed higher mean values at Site 1 (Figure 22). While intersite salt accumulation differences for the Julian date 30-51 exposure period were pronounced, these differences did not become evident until some time after the first two weeks of that period. The plants received a cumulative 12 hours of critical wind exposure for that two weeks, yet the plant salt accumulations remained constant. The plant salt accumulation difference appeared during the last week of the three week exposure period, after the plants were exposed to an additional 22 hours of cumulative critical wind. However, the tower also operated during the last week for this particular tri-weekly set; exposing the plants to 7 hours of cooling tower drift, in addition to 15 hours of separate exposure to spray module drift.

It is concluded that the PSM had little influence on plant salt accumulation during the first two weeks of the Julian date 30-51 exposure period. While there was a terminal salt accumulation difference among the central transect sites, identification of the PSM contribution

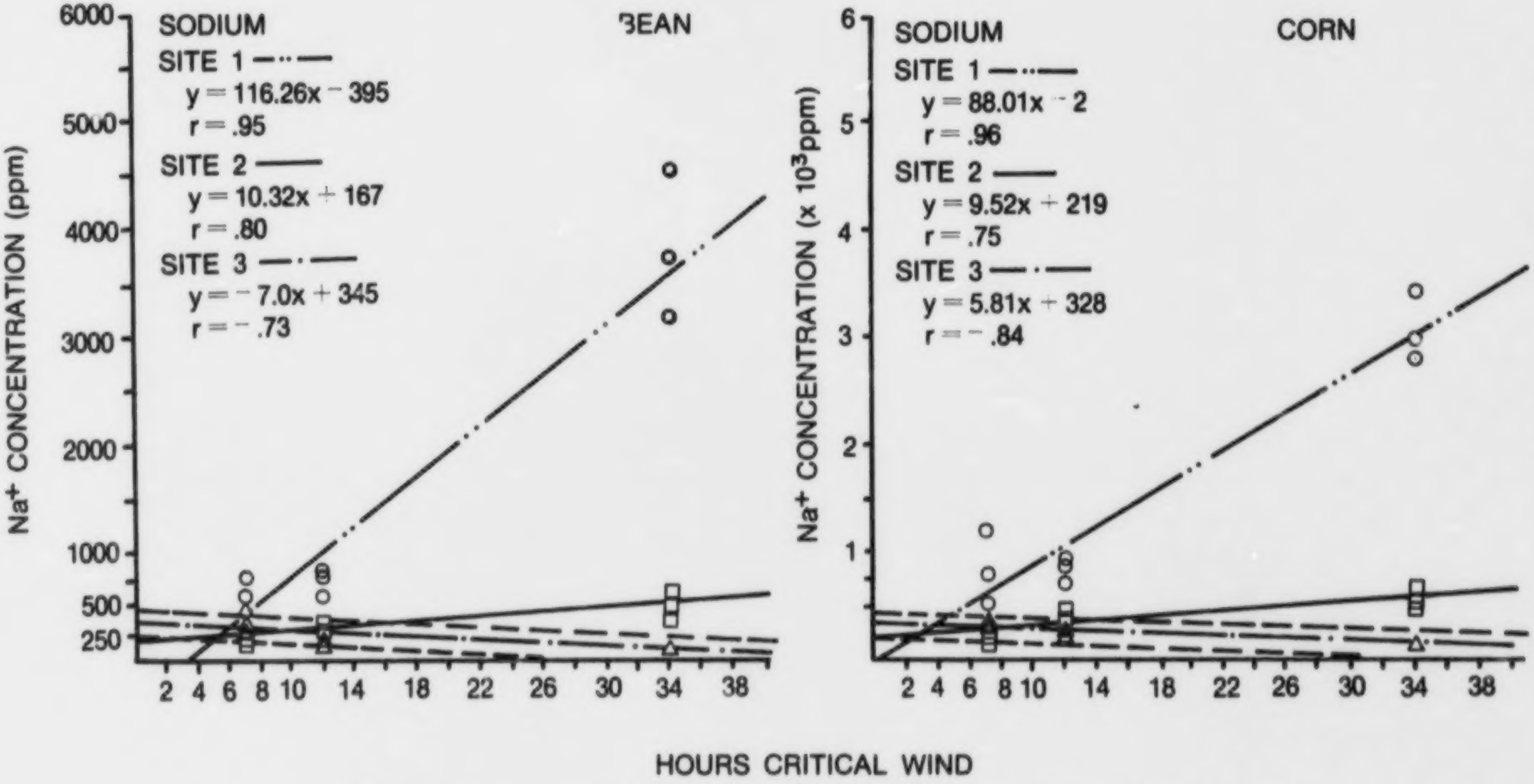


Figure 21. Plot and least squares linear regression of western transect bean and corn sodium concentrations (ppm dry tissue) against wind exposure (hours) at Turkey Point, Florida for period spanning Julian dates 30-51. Dashed line represents centroid-biased 95% confidence interval for site 3 regression line. (○ site 1, □ site 2, △ site 3.)

TABLE 9A. MEAN CHLORIDE ABOVEGROUND ACCUMULATION (PPM DRY WT.) OF BEAN PLANTS FROM JULIAN DATE EXPOSURE GROUP 30-51 AFTER RECEIVING 7, 12, 34 HOURS EXPOSURE TO COOLING DEVICE DRIFT

Site	7 hour	12 hour	34 hour
1	7970	8067	20500
2	6840	6723	9380
3	7130	5707	9043

TABLE 9B. MEAN CHLORIDE ABOVEGROUND ACCUMULATION (PPM DRY WT.) OF CORN PLANTS FROM JULIAN DATE EXPOSURE GROUP 30-51, AFTER RECEIVING 7, 12, 34 HOURS EXPOSURE TO COOLING DEVICE DRIFT

Site	7 hour	12 hour	34 hour
1	14233	15033	17833
2	16700	12300	11053
3	16167	13500	12467

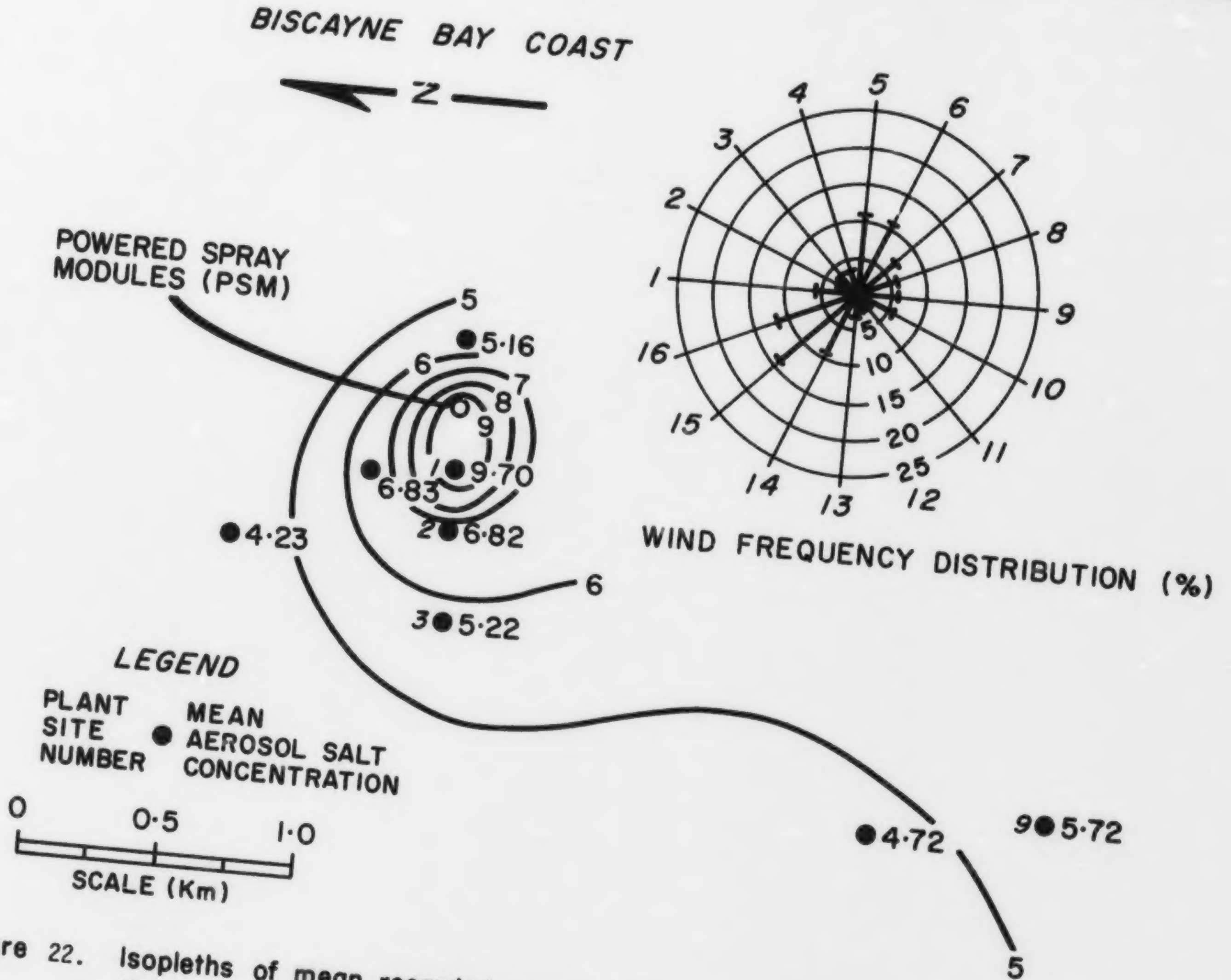

BISCAYNE BAY COAST
N
POWERED SPRAY MODULES (PSM)
5
5·16
6
7
8
9
1 9·70
6·83
2 6·82
4·23
6
3 5·22
4·72
9 5·72
5
LEGEND
PLANT SITE NUMBER ● MEAN AEROSOL SALT CONCENTRATION
0
0·5
1·0
SCALE (Km)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
5
10
15
20
25
WIND FREQUENCY DISTRIBUTION (%)

Figure 22. Isopleths of mean recorded aerosol salt concentrations ($\mu g/m^3$) for the time period 30–51 '74 (Julian date) as measured by an APS Rotary Impaction Sampler. Windrose winds were recorded at the Florida Light & Power Turkey Point weather observing site and are expressed as percent of all hourly observations for the sample period that the wind was from a particular sector (1–16).

was obscured by ambient gradient effect and a possible cooling tower contribution during the last week. Plants of the Julian date 30-51 exposure period along the central transect had roughly equivalent salt accumulations compared to plants from the same sites exposed from Julian dates 51-74. Yet these accumulations resulted from about one-fifth of the critical wind exposure (only 34 hours as compared to 180 hours for the latter period). The cooling tower operated exclusively during the entire Julian date 51-75 period. Since the plant accumulations were comparable for the two exposure periods, the shorter drift exposure time in the earlier period might suggest a comparatively stronger spray module than cooling tower effect at Site 1. However, differing environmental conditions greatly confound the problem of comparing the plant salt concentrations of different drift exposure periods, thus restricting meaningful comparative conclusion. Perhaps reflecting these environmental variables, the Site 1 plants of the Julian date 30-51 exposure period did not exhibit symptoms of salt toxicity, despite having comparable salt accumulations as plants that were injured during earlier exposure periods.

The powered spray modules (PSM) increment to introduced cultivar plant salt accumulations can not be determined with certainty directly from the plant site data. The statistical analysis of the APS data indicated the PSM increased the ambient (background) concentration approximately 3 $\mu g/m^3$ at an APS sampling site 430 meters NW of the tower site (43). The large APS sample variance at Site 1 (215 meters west) and Site 2 (430 meters west), or a possible asymmetrical aerosol dispersion, prevented identifying any PSM increment at those sites. While the Site 2 plants did not show any significant difference from the conservative background at Site 3, the Site 1 plant salt accumulations were significantly higher. However, the paucity of sited plant data prohibits separating the ambient gradient and cooling device increment at Site 1. The lack of full-term aerosol sampling and uncertain ambient gradient effects restrain assessment of the cooling device aerosol increment to suggesting that if there was any significant PSM increment to plant salt accumulations, it was confined to Site 1 (215 meters downwind).

SECTION VII

PHASE III, CONTROLLED EXPOSURE STUDY

DESIGN AND PROCEDURES

Facilities Description and Exposure Sequence

The principal objective of this experiment was to determine bush bean plant injury and yield reduction from simulated ambient salt aerosol loading. Elemental sodium and chloride accumulations in plant tissue were also measured after exposures to varying aerosol salt concentrations. Considerable caution should be exercised when translating limited, controlled exposure results for application to field observations. There are more possible combinations of variations in significant weather events, temporal aerosol concentrations, and plant status than could ever practically duplicated in exposure chambers. Phase III was not intended to duplicate the temporal salt aerosol concentrations at Turkey Point, but rather to investigate plant response at constant, representative concentrations for a duration approximating possible cooling tower drift exposure at Turkey Point. This is a standard approach which dictates, by intent and necessity of design, a broad interpretation of plant dose-response patterns.

Bush bean plants of the same variety exposed at Turkey Point field sites in Phase II were grown in a greenhouse from seeds sown in four-inch plastic pots filled with Jiffy Mix. The greenhouse temperature was 20 ± 5°C and RH 40 ± 10% with unsupplemented natural light (about 700 fcps). Three groups of 100 plants were grown to ages of one, three, and five weeks. Because all plants were harvested at maturity (nine weeks), the groups are best identified by these respective ages at the start of the exposure (see Table 10).

Plants were randomly selected from each of the three age groups, assigned identification numbers, and randomly transferred to the specially designed exposure chambers. All exposures began on the same day. Treatments consisted of three aerosol concentrations (5.25, 75 $\mu g/m^3$) with seven plant replicates per age category for each treatment--a total of 63 plants. Growth conditions in the exposure room were 24 ± 2°C and 57% RH during the light photoperiod, 22 ± 4°C and 45% RH during the dark photoperiod, with 1700 fcps fluorescent-incandescent lights on an 8-hour daily photoperiod. The plants were exposed five hours daily from 10:00 a.m. to 3:00 p.m. during the normal five-day work week, for an accumulation of 100 hours of exposure over a four week period.

At the end of each exposure period, routine growth and chemical composition information was gathered. Abnormal growth and development or plant damage was quantitatively estimated and recorded as it occurred. Additional anatomical examinations measured cell plasmolysis in leaf sections.

TABLE 10. SCHEDULE OF PLANT AND EXPOSURE DURING PHASE III. PLANTS GROUPED BY AGE AT TIME OF EXPOSURE INITIATION

Plant Age (weeks)	Date Planted	Date Exposed	Date Harvested
One	11/25/74	12/2-30/74	1/28/75
Three	11/11/74	12/2-30/74	1/13/75
Five	10/28/74	12/2-30/74	1/02/75

Three exposure units, one for each aerosol concentration consisted of rotating tables 1.8 meters in diameter that rotated 16 times per hour (Figures 23 thru 28). The potted plants were located single file around the table perimeter where they revolved through a spray booth (equipped with 81 x 46 cm openings on both sides) equipped with an air atomized spray nozzle (Sonocord 035H) which generated the sea salt aerosol (diluted 1:30). The sea water for the salt aerosol was collected at the Oregon Pacific Coast. Net room air flow was positively directed up the aerosol gradient and exhausted out a door vent through a filtered circulation fan.

During weekends and following full exposure, the plants were placed in growth chambers with a temperature of 21 ± 2°C, 47% RH, and 2100 fcps of fluorescent-incandescent light on a 12 hour photoperiod. In both exposure and growth chambers, the plants received half-strength Hoagland nutrient solution, at least once every two days. When the plants reached nine weeks of age, they were removed from the growth chambers, weighted, and then assayed for salt component concentration (34).

The plants shared common environmental conditions throughout the salt spray exposure. Plants were then maintained in growth chambers during the post-exposure period, which possessed relatively more light and different nutrient schedule than the greenhouse. The plants remained in the growth chamber until they reached maturity so that full term effects of exposure could be determined. Since the plants were of three ages, there were three harvest groups at different times as the plants matured over a 9 week period. Each harvest group spent different amounts

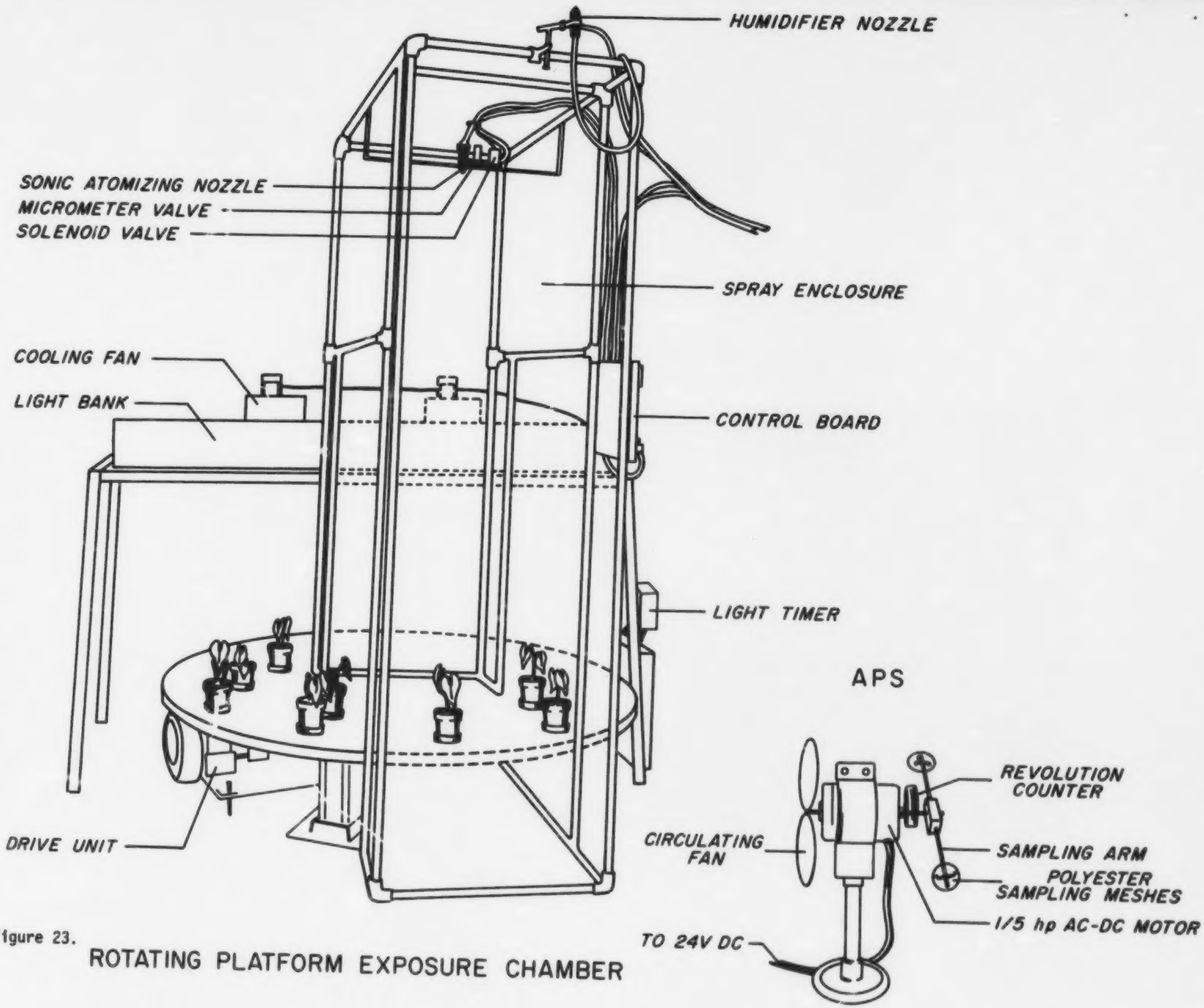

HUMIDIFIER NOZZLE
SONIC ATOMIZING NOZZLE
MICROMETER VALVE
SOLENOID VALVE
SPRAY ENCLOSURE
COOLING FAN
LIGHT BANK
CONTROL BOARD
LIGHT TIMER
APS
DRIVE UNIT
REVOLUTION COUNTER
CIRCULATING FAN
SAMPLING ARM
POLYESTER SAMPLING MESHES
1/5 hp AC-DC MOTOR
TO 24V DC

Figure 23.
ROTATING PLATFORM EXPOSURE CHAMBER

Figure 24. Saline aerosol exposure chamber with salt spray nozzle in operation.

PUMP STATION

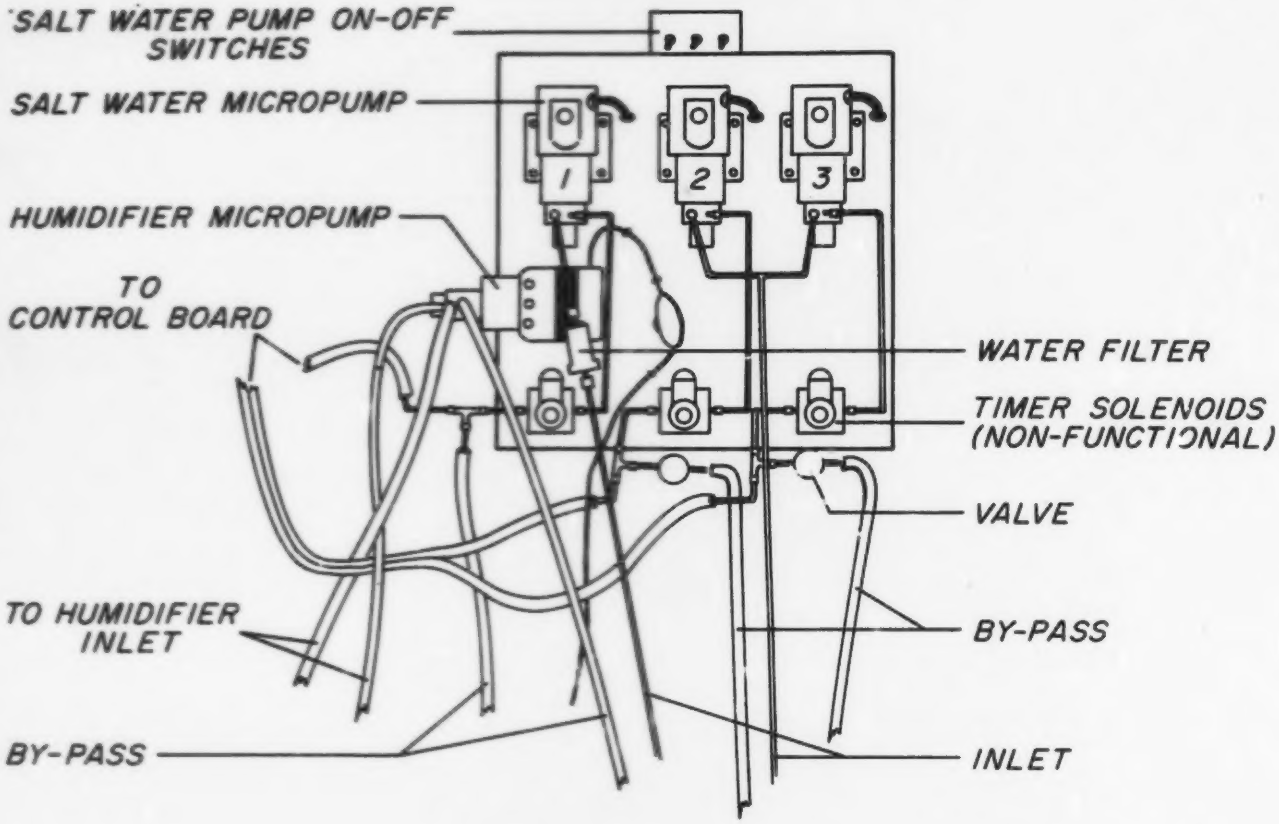

SALT WATER PUMP ON-OFF SWITCHES
SALT WATER MICROPUMP
1
2
3
HUMIDIFIER MICROPUMP
TO CONTROL BOARD
WATER FILTER
TIMER SOLENOIDS (NON-FUNCTIONAL)
VALVE
TO HUMIDIFIER INLET
BY-PASS
BY-PASS
INLET

FIGURE 25A.

CONTROL BOARD

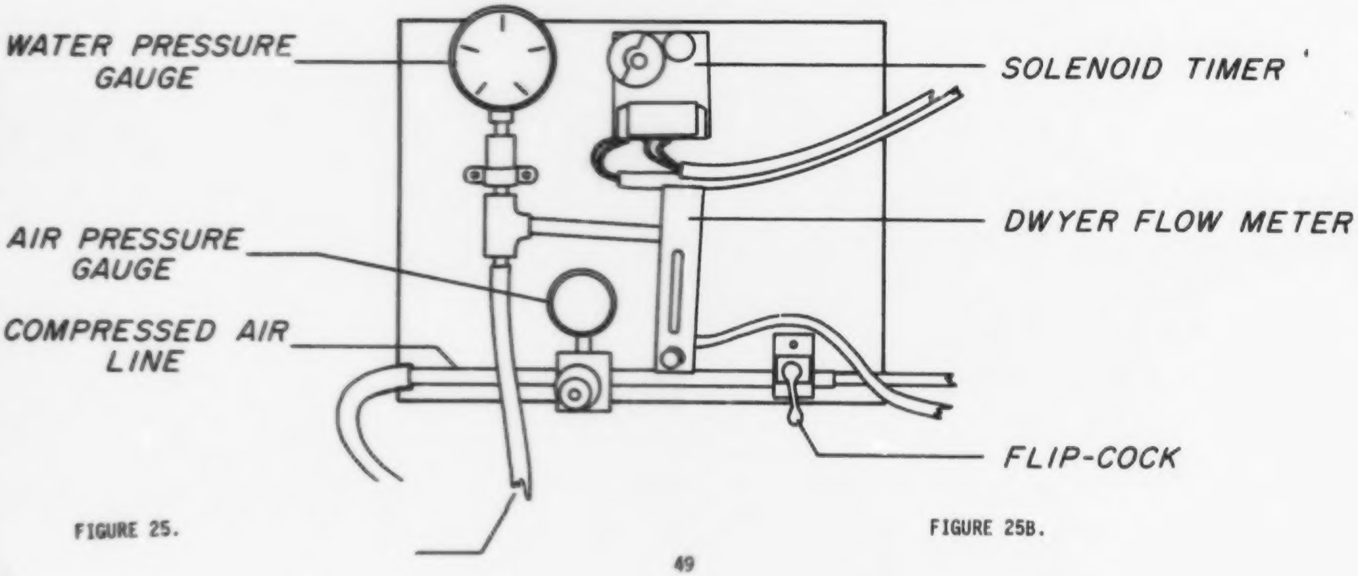

WATER PRESSURE GAUGE
SOLENOID TIMER
DWYER FLOW METER
AIR PRESSURE GAUGE
COMPRESSED AIR LINE
FLIP-COCK

FIGURE 25.

FIGURE 25B.

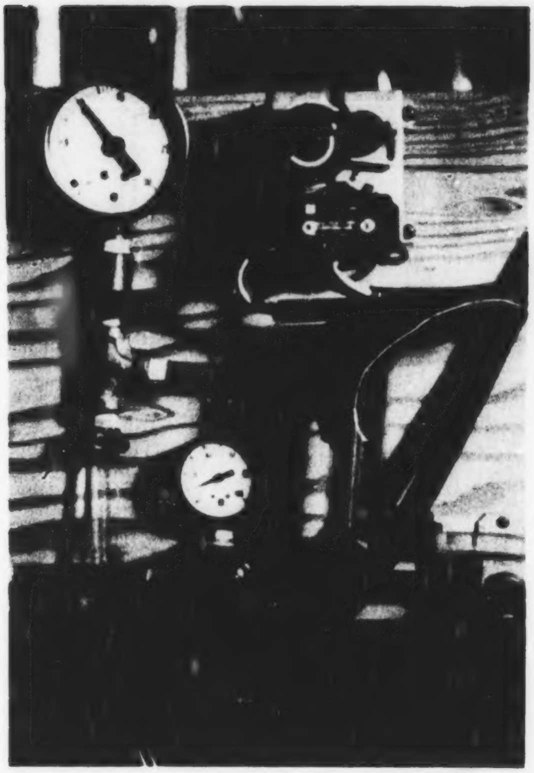


Figure 26. A control board of a phase 3 exposure chamber.

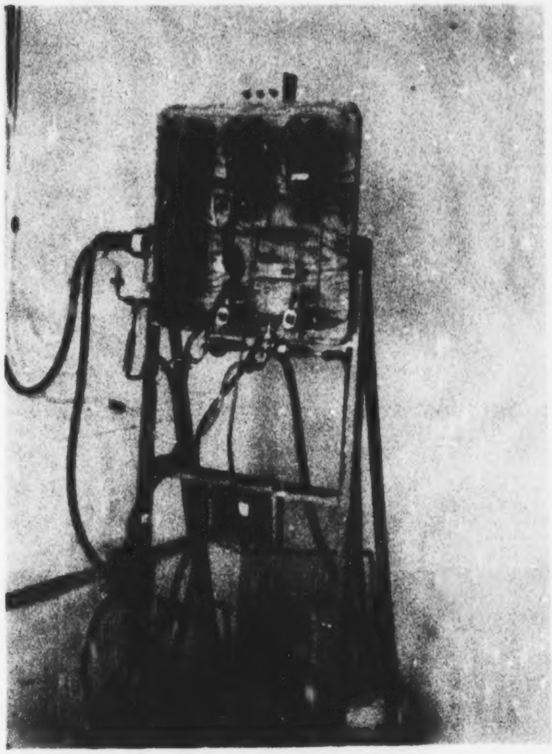


Figure 27. Salt water pump station used in Phase 3 experiment.

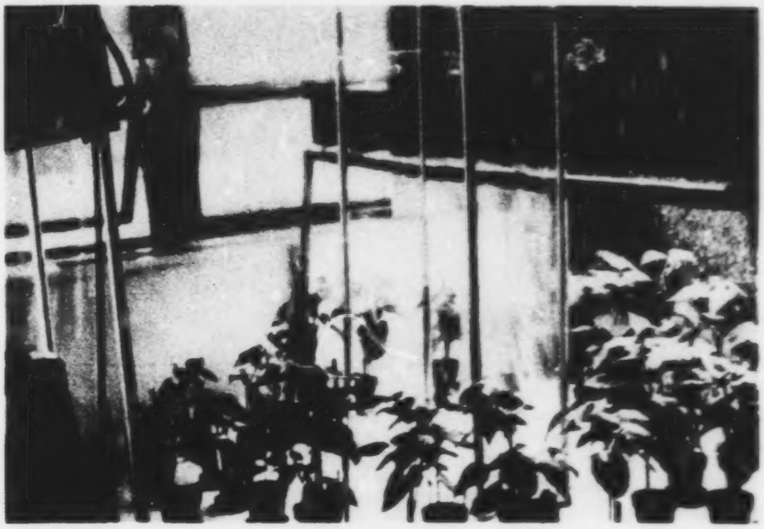


Figure 28. Bush bean plants on exposure chamber turn-table.

Figure 29. APS apparatus used to monitor salt aerosol concentrations during plant exposure.

of time in the growth chamber; 3 days, 16 days and 29 days for the plants where exposure began at age 5 weeks, 3 weeks, and 1 week, respectively. Consequently, the general increase in plant mass with decreasing age at exposure reflected longer stays in the more favorable growth conditions in the growth chamber, obscuring interage differences caused by salt aerosol stress. Except for general trends, comparisons of plants of different ages should not be attempted beyond termination of salt aerosol exposure.

Aerosol Sampling

The same Airborne Particle Sampler (APS) that was employed in the Turkey Point field studies was also used to sample sea salt aerosol concentration in the controlled exposure chambers (Figure 29). The APS employs inertial impaction to collect aerosols on rotating pairs of polyester meshes (44).

APS operation within the confines of a laboratory caused some initial concern regarding validity of the measured aerosol concentrations. Therefore, measurements with the APS method were compared with simultaneous measurements by the Isokinetic Sampling System (IK), also an Environmental Systems Corp. product. The IK incorporates a heated sampling tube filled with small glass beads. A pump-gas meter combination maintains an isokinetic airflow, drawing it over a heater wire that evaporates the aerosol and deposits the salt in the interior of the tube. When the exposure is terminated the tube is flushed with distilled water and subsequently analyzed for Na+ by atomic absorption spectroscopy.

During a one week test period preceeding the plant exposure study, ESC personnel conducted comparisons of these samplers in the exposure chambers at the EPA facilities in Corvallis. Comparison of the results of five simultaneous measurement pairs, shown on Table 11, indicated no significant difference between the two techniques on the revolving tables. The APS method was selected as the aerosol monitoring method for Phase III because of continuity, convenience and cost.

Salt aerosol concentrations during plant exposure were monitored with the APS/24 VDC battery pack in position near the perimeter of revolving exposure tables. The concentration levels were calibrated prior to plant exposure. The salt levels were monitored preceeding and following each week the bean plants were exposed. APS sampling time averaged at least 30 minutes for each spray chamber. The APS was mounted at plant height with the sampling arm portion of the APS head directed forward with respect to the direction of table revolution. The meshes were removed from the APS sampling arm with plastic forceps and placed in chemically sterile 150 ml beakers. The beaker mouths were then covered with "parafilm" to minimize procedural Na+ background. The

TABLE 11. WILCOX ON MATCHED-PAIR SIGNED-RANK TEST OF SALT AEROSOL CONCENTRATIONS IN A EXPOSURE CHAMBER (OVER A RANGE OF PERFORMANCE SETTINGS) DETERMINED BY SIMULTANEOUS MEASUREMENT WITH AN AIRBORNE PARTICLE SAMPLER (APS) AND ISOKINETIC SAMPLER (IK)

	Salt Aerosol Concentration ($\mu g/m^3$)		Difference		
Pair	APS	IK	D	Rank of IDI	T
1	69	88	-19	5	5
2	140	137	3	3	
3	57	64	-7	4	4
4	24	23	1	1.5	
5	32	31	1	1.5	
					$T = 9^{NS}$

TABLE 12. RELATIVE PARTICLE SIZE DISTRIBUTION OF SEA SALT AEROSOL GENERATED WITH A SONICORD 035H AT 10 PSI IN A ROTATING TABLE EXPOSURE CHAMBER AS DETERMINED FROM MAGNESIUM OXIDE SLIDES PLACED AT PLANT HEIGHT

Percent of particle diameter with impact crater (μm)			
< 50	50-100	> 100-150	> 150
46%	44%	7.4%	2.6%

Average particle size: 58 μm

meshes were eluted with 50 ml 10% HCl solution, sonicated 30 seconds, and allowed to stand 30 minutes before Na+ determination by atomic absorption spectrophotometry. The sea salt aerosol concentration was computed as:

$$\phi_{\text{sea salt}} = 3.267 \left(\frac{M_{Na} - M_{BNa}}{V}\right) [\mu g/m^3]$$

where:

M_{Na} is the mass of sodium collected by the mesh pairs

M_{BNa} is the Na+ procedural background

V is the sampled air volume

Slides coated with magnesium oxide were used to estimate particle size distribution (45). Each slide was prepared by passing a clean 7.5 cm x 2.5 cm glass microscope slide through a flame produced by igniting a metal screen of about six magnesium turnings (Grignard reagent grade) until a light coating of oxide was visible. For about 2-3 minutes the slides, coated surface up, were placed above the turntable at the same height as the plant, then removed and returned to the laboratory. Using a microscope equipped with a calibrated ocular micrometer, ten fields of each slide were examined to measure the diameter of all the impact craters in each field (Table 12). Figure 30 gives a representative illustration of the craters.

A 1.5 cm x 2.5 cm slide without a coating was placed at the same height as the plant and exposed to salt spray. Microscopic examination showed droplets under high humidity and crystals under low humidity (Figure 31). The crystals resembled those found under the epidermal layer of the bush bean plant exposed to salt aerosol.

RESULTS AND DISCUSSION

Plant Injury

Description--Visual examination of bush beans revealed chlorosis with crinkling and yellowing in older leaves similar to that observed at Turkey Point. Bleached spots caused by chlorophyll disintegration also were noticed on the upper surface of the bean leaf (Figures 32 and 33). Marginal wilting (Figure 34 and 35) not distinguishable from drought injury, developed more on older than on younger leaves of plants during exposure to salt aerosol in the controlled exposure experiment. After a few days, the affected leaves showed curling on the margins and tips (Figure 36). Chlorotic and necrotic areas developed unevenly over the entire surface of the leaf. These symptoms suggest that salt deposition on the leaves diffused throughout the epidermis causing chloroplasts to

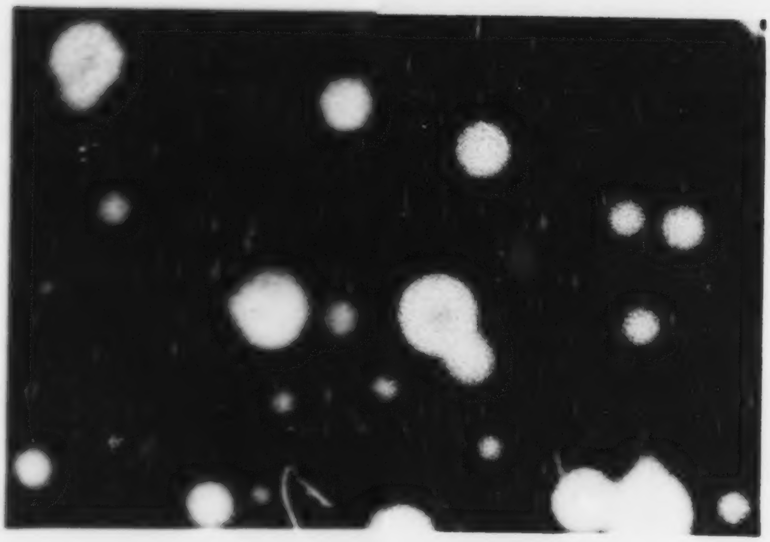


Figure 30. Aerosol impaction craters on Magnesium Oxide-coated slide. (x 450).

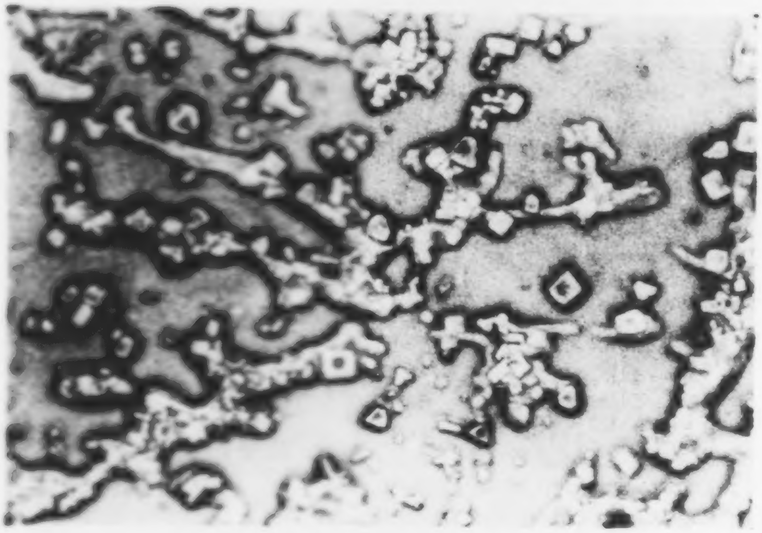


Figure 31. Salt crystals shown on the upper surface of bean leaf exposed to 75 µg/m^3 salt spray. (x 450)

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Figure 32. Tip and marginal necrosis with spotting on bush bean leaf exposed to salt aerosol.

Figure 33. Bleaching of tissue on upper surface of bush bean leaf exposed to salt aerosol.

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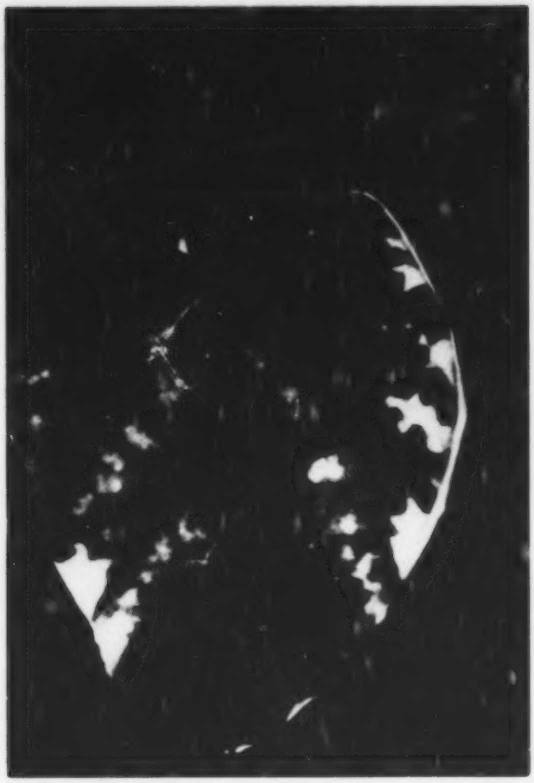

Figure 34. Primary leaf of bush bean exhibiting marginal wilting and other various degrees of injury by saline aerosol.

Figure 35. Marginal and intercostal tissue collapse on bush bean exposed to a salt spray concentration of 75 μg/m^3 for 100 hours.

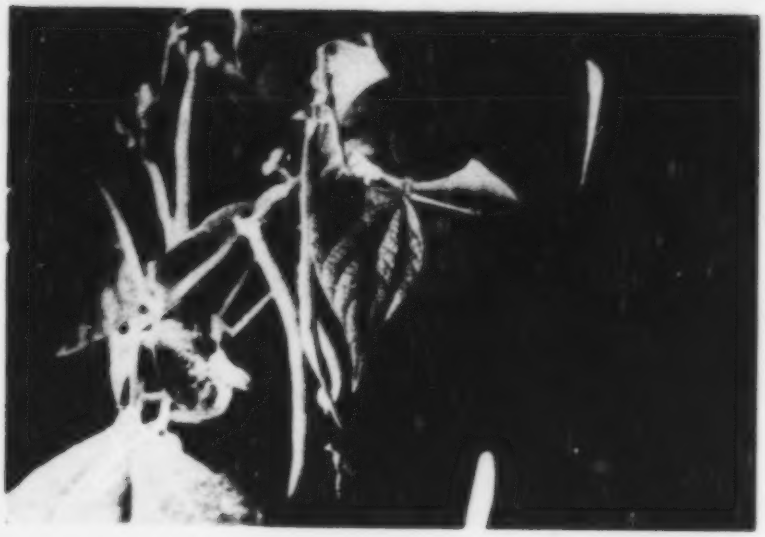

Figure 36. Seven week old bush bean exhibiting injury on trifoliate leaf of plant exposed to 75 µg/m^3 for about 50 hours.

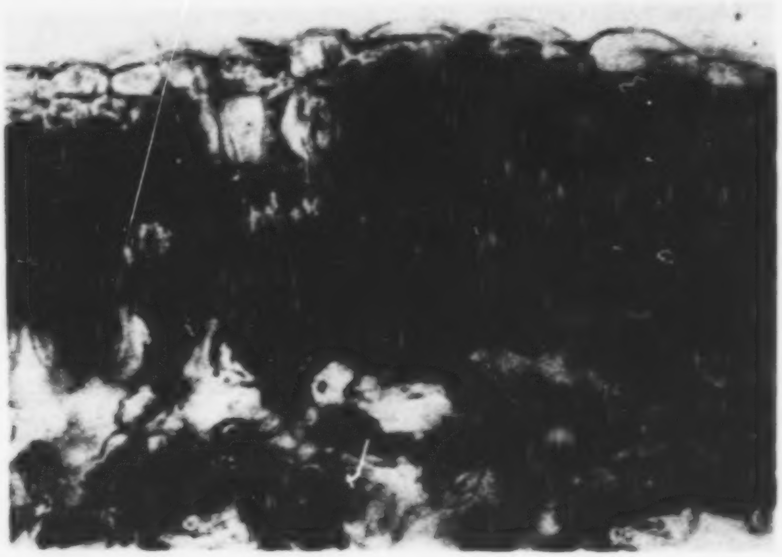

Figure 37. Microscopic cross section of bush bean leaf shows salt aerosol injury. The palisade cells have plasmolyzed and lost their integrity, while the epidermis cells remained intact. (x 450)

disintegrate. Occasionally water-logged areas on the leaf appeared immediately after high salt deposition, but most of these symptoms did not develop into chlorotic or necrotic lesions.

Microscopic examination of salt aerosol injured leaf tissues revealed that the chloroplasts below the upper epidermis had disintegrated and lost their integrity. The injury extended in most cases to the palisade cells (Figure 37). Under severe conditions, the damage advanced to the adjacent spongy layer whereas the vascular bundles remained intact. Crystals, probably sodium chloride, were clearly observed beneath the epidermis layer between palisade cells and often near the vascular bundles (Figure 38).

Aerosol Concentration and Foliar Injury--Incidence and severity of foliar injury were the basic responses measured to determine bush bean growth sensitivity to salt aerosol. There was a general increase in foliar injury noted on the plants as exposure was initiated on later stages of growth. For any particular treatment, the plants exposed initially at 5 weeks after germination exhibited the most trifoliate leaf injury, followed by the plants exposed initially at three weeks, then those at one week. Due to the leafing sequence characteristic of the bush bean, the upper canopy trifoliates were selected as more representatively expressing area of foliar stress than the lower, younger leaves.

The severity of injury on the canopy trifoliates appeared exponentially related ($r \geq .79$ for all weeks, $P < 0.01$) to aerosol concentration over the range of exposures used (Figure 39). The severity of injury for all three stages of growth exhibited similar response trends, increasing with age for a given concentration and increasing abruptly when the salt concentration exceeded 25 $\mu g/m^3$. The severity of injury on the five week plants in contrast to other age groups was statistically significant ($P < 0.05$), though with never more than 7% average area of trifoliate injury separating the three ages with any treatment. The older canopy trifoliate leaves were effectively exposed for longer periods with more impingement surface area. The trifoliates of the younger, developing plants emerged during the exposure period and had the opportunity to disperse at least some fraction of the surface accumulation of sea salt through growth expansion while presenting an overall smaller surface area.

The incidence of injury on all the trifoliate leaves showed a more linear response across the salt aerosol exposure gradient than did severity of injury (Figure 40). A leaf was classified as injured based on visual symptoms. All the trifoliates for each plant were examined by age group and aerosol treatment. Results indicated a strong correlation

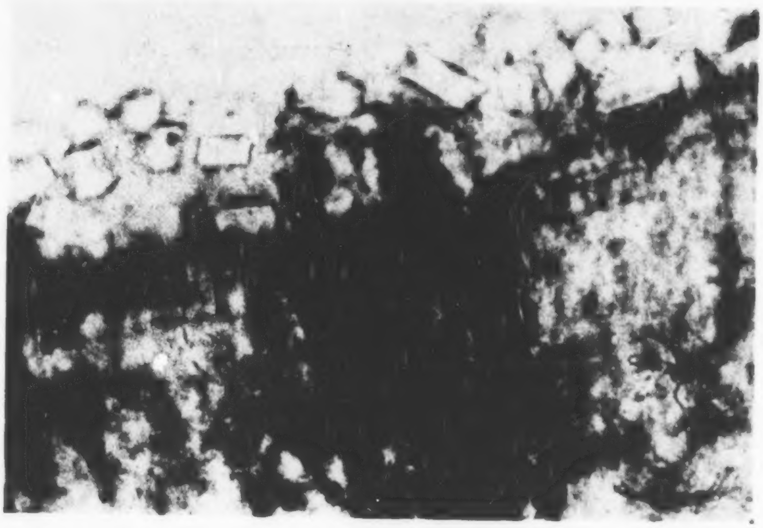

Figure 38. Microscopic cross-section of bush bean leaf shows salt aerosol injury. The mesophyll cells have plazmolyzed and lost their integrity, but the epidermal cells remained intact. Crystals, probably sodium chloride, clearly shown below the epidermis and adjacent to vascular bundles. (X 450)

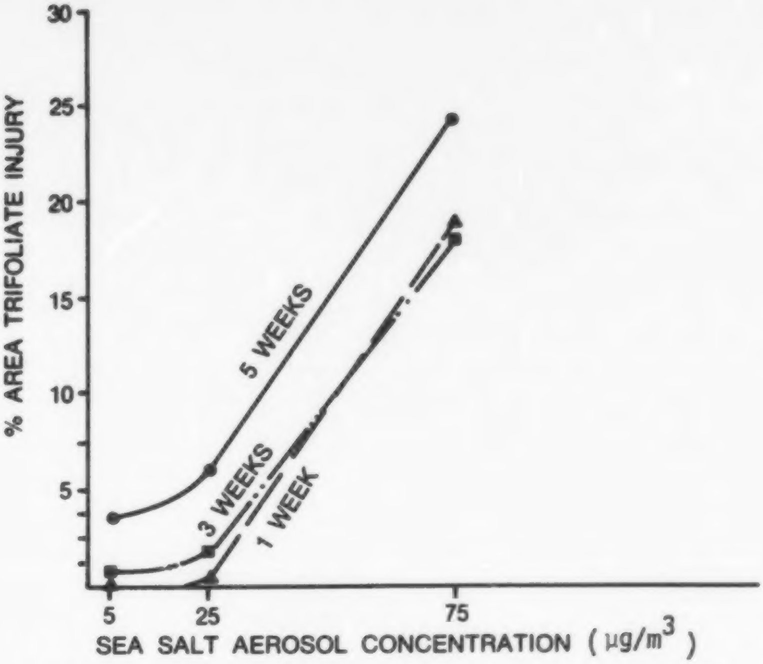

Figure 39. Mean percentage foliar area injured on the first three sets of trifoliate leaves of three ages of bush bean (*Phaseolus vulgaris* L.) after 100 hours exposure to various sea salt aerosol concentrations. (Exposure initiated at: —●— 5 weeks, —··■··—, 3 weeks, ––▲––, 1 week.)

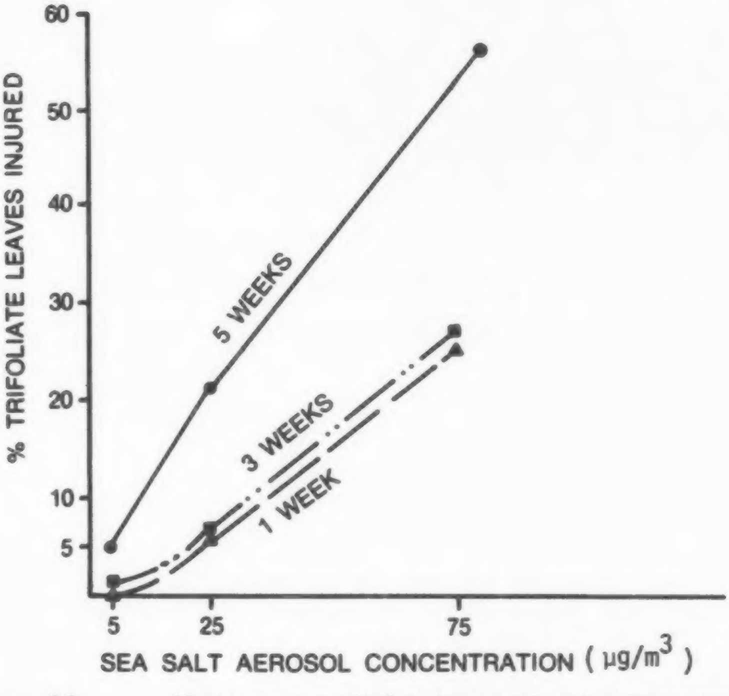

Figure 40. Mean percent trifoliate leaves injured on three ages of bush bean (*Phaseolus vulgaris* L.) after 100 hours exposure to different sea salt aerosol concentrations. (Exposure initiated at: —●— 5 weeks, —··■··—, 3 weeks, ––▲––, 1 week.)

($r > .92$ for all weeks, $P < 0.01$) between incidence of trifoliate injury and salt aerosol concentration. As with severity of injury, the more mature plants exhibited a higher incidence of trifoliate leaf injury for a given salt aerosol concentration. The 5 week old plants had an incidence of injury significantly higher ($P < 0.01$) at all treatments than the other ages.

Table 13 shows the effects of 100 cumulative hours of simulated sea salt aerosol exposure on the canopy trifoliate leaves. The five week plants had a trace (0 -5%) injury threshold below 5 $\mu g/m^3$, the lowest concentration used. The trace injury threshold of the upper trifoliates for the three week and one week plants was near 5 $\mu g/m^3$ and 25 $\mu g/m^3$, respectively. Examination of the injury incidence for all trifoliates yielded the same trace injury threshold as severity of upper trifoliate injury (Table 14). Evaluation of the injury incidence with the log of treatment concentrations yielded a threshold distribution that is generally more meaningful over a range of sensitivity than simply focusing on a single threshold. The small number of treatments did not warrant elaborate statistical analysis of a log dose-response nature. However, a few general conclusions can be drawn from what data was gathered. The dose-response (Figure 41) plots for the different ages were closely parallel, with the plot for five week old plants illustrating the increased sensitivity with age. The median effective dose (ED 50) for the five week old plants is near 70 $\mu g/m^3$. While the ED 50 for the other two ages is roughly 165 $\mu g/m^3$, better than a factor of two higher than that of the five week old plants. Severity of injury on most of the affected trifoliate leaves was from 5% to 10%, though some of the canopy trifoliate leaves had 50% of their surface injured.

FOLIAR SALT CONCENTRATION AND INJURY

Salt concentration of the unwashed trifoliate leaves closely corresponded to the treatment concentrations. The five-week old plants had the highest Na^+ and Cl^- leaf concentration at harvest, followed by the three-week and one-week old plants (see Tables 15-17). Since the five-week old plants had less post-exposure opportunity than the younger plants for ion translocation and growth prior to harvest, their high leaf concentration best reflected the relationship between treatment and leaf concentration of the salt. Salt concentration in the five-week old trifoliates was directly proportional ($r > .94$, $P < 0.01$) to the concentration of the salt aerosol (see Figure 42). The Na^+ and Cl^- concentrations in the younger plants showed a similar relationship ($r > .89$ Na^+, $r = .80$, Cl^-, $P < 0.01$) between increased foliar concentration and salt aerosol concentration.

TABLE 13. MEAN PERCENTAGE OF FOLIAR AREA INJURY ON UPPER TRIFOLIATES OF THREE STAGES OF GROWTH OF BUSH BEANS EXPOSED 100 HOURS TO THREE CONCENTRATIONS OF SALT AEROSOL

Age at Initiation of Exposure	5 $\mu g/m^3$	25 $\mu g/m^3$	75 μ/m^3
One Week	0^{ac}	$.3^{ac}$	18.7^{bc}
Three Week	$.7^{ac}$	1.7^{ac}	17.6^{bc}
Five Week	3.6^{ad}	5.9^{ad}	24.0^{bc}

Percent area foliar injury followed by the same letter (a or b in row; c or d in a column) do not differ significantly at the 5% level according to the Duncan Multiple Range test.

TABLE 14. PROPORTION OF TRIFOLIATE LEAVES INJURED AFTER 100 HOURS INTERMITTENT EXPOSURE TO A SALINE AEROSOL GENERATED BY A SONICORD NOZZLE AT 5 $\mu g/m^3$, 25 $\mu g/m^3$, 75 $\mu g/m^3$ AT THREE STAGES OF GROWTH

Concentration	Age	Leaves Injured	Total Leaves	Percent Injury
5 $\mu g/m^3$	1 week	0	54	0^a
	3 week	1	81	1^a
	5 week	6	130	4.6^b
25 $\mu g/m^3$	1 week	3	50	6^a
	3 week	5	78	6.4^a
	5 week	19	90	21^b
75 $\mu g/m^3$	1 week	15	60	25^a
	3 week	23	84	27^a
	5 week	49	90	55^b

Percent Injury, within a specific concentration column, followed by the same letter (a or b) do not differ significantly at the 1% (or 5%) level according to the Duncan Multiple Range Test.

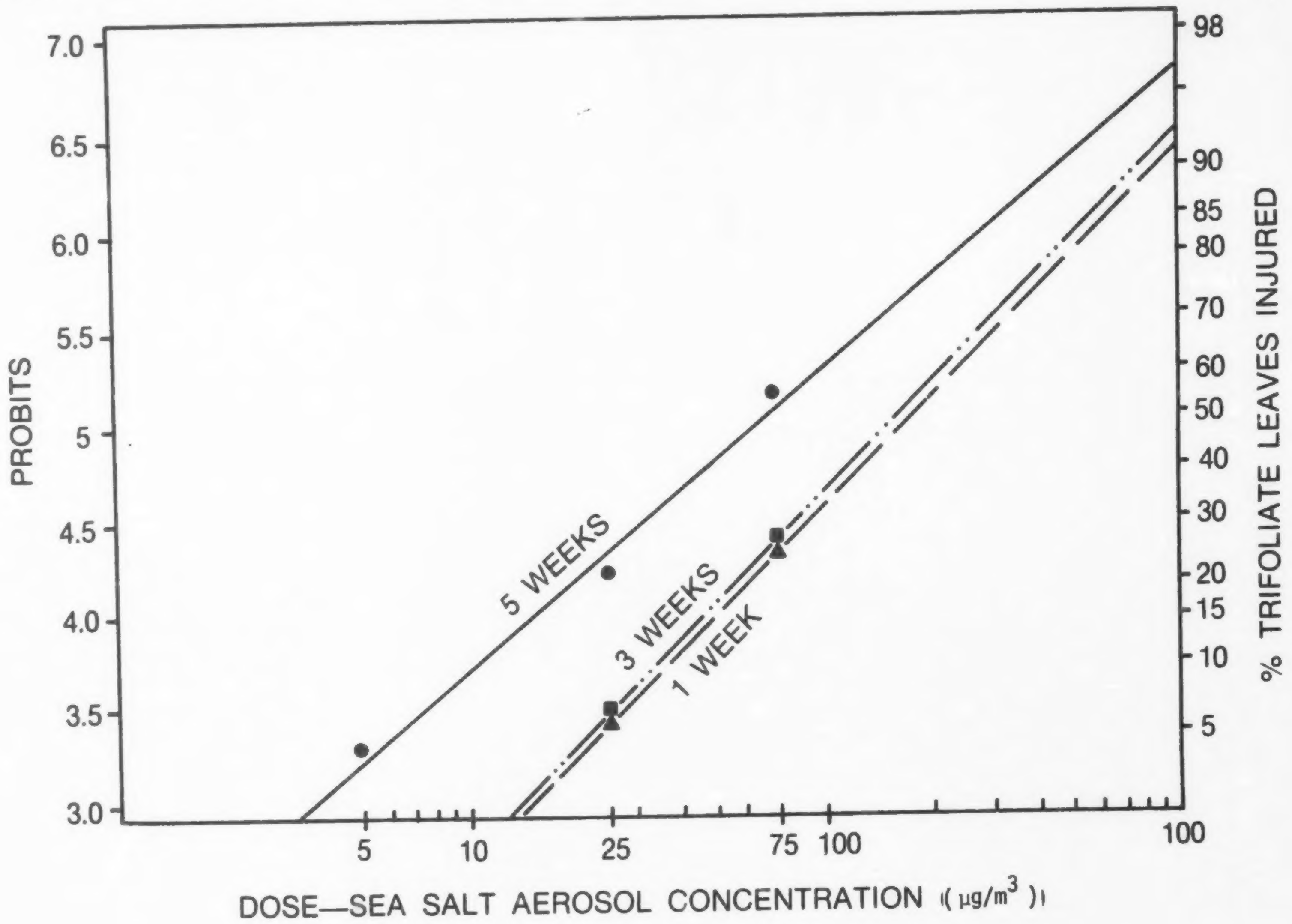

Figure 41. Log dose-response plot for bush bean *Phaseolus vulgaris* L.) trifoliate leaves injured following exposure to three concentrations of sea salt aerosol for 100 hours at different stages of growth. ED^{50}represents the concentration where 50% of all trifoliate leaves exhibit injury.

TABLE 15. SUMMARY OF CONTROLLED EXPOSURE RESULTS FOR MATURE BUSH BEAN INITIALLY EXPOSED AT FIVE WEEKS OLD FOR A CUMULATIVE 100 HOURS TO SEA SALT AEROSOL DURING A FOUR WEEK PERIOD. SUMMARY LISTS MEAN SEVERITY OF TRIFOLIATE INJURY (%), MASS (GREEN AND DRY IN GRAMS), POD PRODUCTIVITY AND SALT CHEMICAL ANALYSIS FOR PLANT SEGMENTS AND SOIL (PPM DRY WT.)

Average of 7 Plants		5 $\mu g/m^3$	25 $\mu g/m^3$	75 $\mu g/m^3$
Average percent of 1st, 2nd, and 3rd set trifoliate injury		3.6	5.9	24.0**
Weight of 1-3 set of trifoliate leaves	green	9.81 (± 2.10)[1]	8.3 (± 1.34)	5.10 (± 1.44)**
	dry	1.74 (± 0.34)	1.57 (± 0.23)	1.21 (± 0.22)**
Chemical analysis	Cl^-	2789	6254	40700
	Na^+	102	914	12143
Leaf weight	green	8.39 (± 3.29)	11.25 (± 2.53)	8.23 (± 3.42)
	dry	1.17 (± 0.66)	1.86 (± 0.60)	1.37 (± 0.58)
Chemical analysis	Cl^-	3770	5543	20171
	Na^+	158	601	5089
Stem weight	green	9.89 (± 2.12)	9.88 (± 1.07)	1.42 (± 2.25)
	dry	1.81 (± 0.60)	2.06 (± 0.46)	1.54 (± 0.40)
Chemical analysis	Cl^-	3771	3786	7560
	Na^+	1119	1899	8581
Pods and seed weight	green	24.36 (± 9.51)	30.76 (± 9.31)	19.31 (± 7.48)
	dry	3.48 (± 0.87)	3.86 (± 1.20)	2.94 (± 0.93)
Chemical analysis	Cl^-	1956	2134	2444
	Na^+	80	244	2634
Average number of healthy pods		3.14 (± 0.90)	3.71 (± 1.11)	2.94 (± 0.79)
Average number of seeds		10.43 (± 3.31)	12.71 (± 3.64)	9.29 (± 3.25)
Roots chemical analysis	Cl^-	390	309	434
	Na^+	1114	710	1085
Soil Chemical Analysis	Cl^-	202	257	360
	Na^+	548	705	732

[1] arithmetic mean (± 1 SD)

*indicates inter-row significant difference ($P < 0.05$)

**indicates inter-row highly significant difference ($P < 0.01$)

TABLE 16. SUMMARY OF CONTROLLED EXPOSURE RESULTS FOR MATURE BUSH BEAN INITIALLY EXPOSED AT THREE WEEKS OLD FOR A CUMULATIVE 100 HOURS TO SEA SALT AEROSOL DURING A FOUR WEEK PERIOD. SUMMARY LISTS MEAN SEVERITY OF TRIFOLIATE INJURY (%), MASS (GREEN & DRY IN GRAMS) POD PRODUCTIVITY, AND SALT CHEMICAL ANALYSIS FOR PLANT SEGMENTS AND SOIL (PPM DRY WT.)

Average of 7 Plants		5 $\mu g/m^3$	25 $\mu g/m^3$	75 $\mu g/m^3$
Average percent of 1st, 2nd and 3rd set trifoliate injury		.7	1.7	17.6**
Weight of 1-3 set of trifoliate leaves	green	6.8 (± 2.65)[1]	5.90 (± 2.01)	6.51 (± 2.38)
	dry	0.94 (± 0.33)	0.93 (± 0.24)	1.05 (± 0.25)
Chemical analysis	Cl^-	2014	6717	32886
	Na^+	204	496	5820
Leaf weight	green	10.42 (± 5.11)	7.32 (± 2.51)	11.43 (± 8.93)
	dry	1.16 (± 0.71)	0.90 (± 0.38)	1.51 (± 1.33)
Chemical analysis	Cl^-	2856	5564	17321
	Na^+	169	375	2243
Stem weight	green	10.08 (± 3.27)	9.19 (± 1.54)	11.08 (± 4.39)
	dry	1.44 (± 1.17)	1.68 (± 0.48)	1.86 (± 1.16)
Chemical analysis	Cl^-	2600	7033	6869
	Na^+	776	1958	3036
Pods and seed weight	green	23.80 (± 5.16)	23.22 (± 4.09)	22.14 (± 8.89)
	dry	4.16 (± 1.36)	4.16 (± 1.37)	4.20 (± 2.34)
Chemical analysis	Cl^-	1357	1260	1680
	Na^+	70	110	2257
Average number of healthy pods		4.0 (± 0.82)	3.57 (± 1.28)	3.86 (± 2.34)
Average number of seeds		13.57 (± 4.11)	12.14 (± 3.19)	12.43 (± 7.59)
Roots chemical analysis	Cl^-	485†	465†	656†
		2157	2673	4411
Soil chemical analysis	Cl^-	753†	1365†	840†
	Na^+	814	1165	770

[1] arithmetic mean (± 1 SD)

† actual value less than the number listed

* indicates inter-row significant difference ($P < 0.05$)

** indicates inter-row highly significant difference ($P < 0.01$)

TABLE 17. SUMMARY OF CONTROLLED EXPOSURE RESULTS FOR MATURE BUSH BEAN INITIALLY EXPOSED AT ONE WEEK OLD FOR A CUMULATIVE 100 HOURS TO SEA SALT AEROSOL DURING A FOUR WEEK PERIOD. SUMMARY LISTS MEAN SEVERITY OF TRIFOLIATE INJURY (%), MASS (GREEN AND DRY IN GRAMS), POD PRODUCTIVITY AND SALT CHEMICAL ANALYSIS FOR PLANT SEGMENTS AND SOIL (PPM DRY WT.)

Average of 7 Plants		5 μg/m^3	25 μg/m^3	75 μg/m^3
Average percent of 1st 2nd and 3rd set trifoliate		0	0.3	18.7**
Weight of 1-3 set of trifoliate leaves	green	10.25 (± 1.90)[1]	9.12 (± 1.65)	10.34 (± 2.38)
	dry	1.59 (± 0.28)	1.42 (± 0.04)	1.54 (± 0.29)
Chemical analysis	Cl^-	1148†	957	8630
	Na^+	84	112	889
Leaf weight	green	14.97 (± 3.55)	9.50 (± 5.57)	17.77 (± 8.99)
	dry	2.12 (± 0.74)	1.36 (± 0.78)	2.56 (± 1.19)
Chemical analysis	Cl^-	1450†	2159	6106
	Na^+	128	208	180
Stem weight	green	15.86 (± 3.24)	11.60 (± 3.91)	17.22 (± 4.78)
	dry	3.77 (± 1.12)	2.87 (± 0.99)	4.08 (± 1.02)
Chemical analysis	Cl^-	1035†	729†	1429†
	Na^+	21	32	283
Number of healthy pods		8.29 (± 1.89)	6.29 (± 3.55)	6.57 (± 4.36)
Number of seeds		33.71 (± 6.8)	23.86 (± 16.92)	24.29 (± 17.59)
Roots Chemical Analysis	Cl^-	1272†	900†	1194†
	Na^+	2386	2264	1953
Soil chemical analysis	Cl^-	166†	188†	--
	Na^+	1682	1645	--

[1] arithmetic mean (± 1 SD)

†actual value less than the number listed

*indicates inter-row significant difference ($P < 0.05$)

**indicates inter-row highly significant difference ($P < 0.01$) from non-asterick values

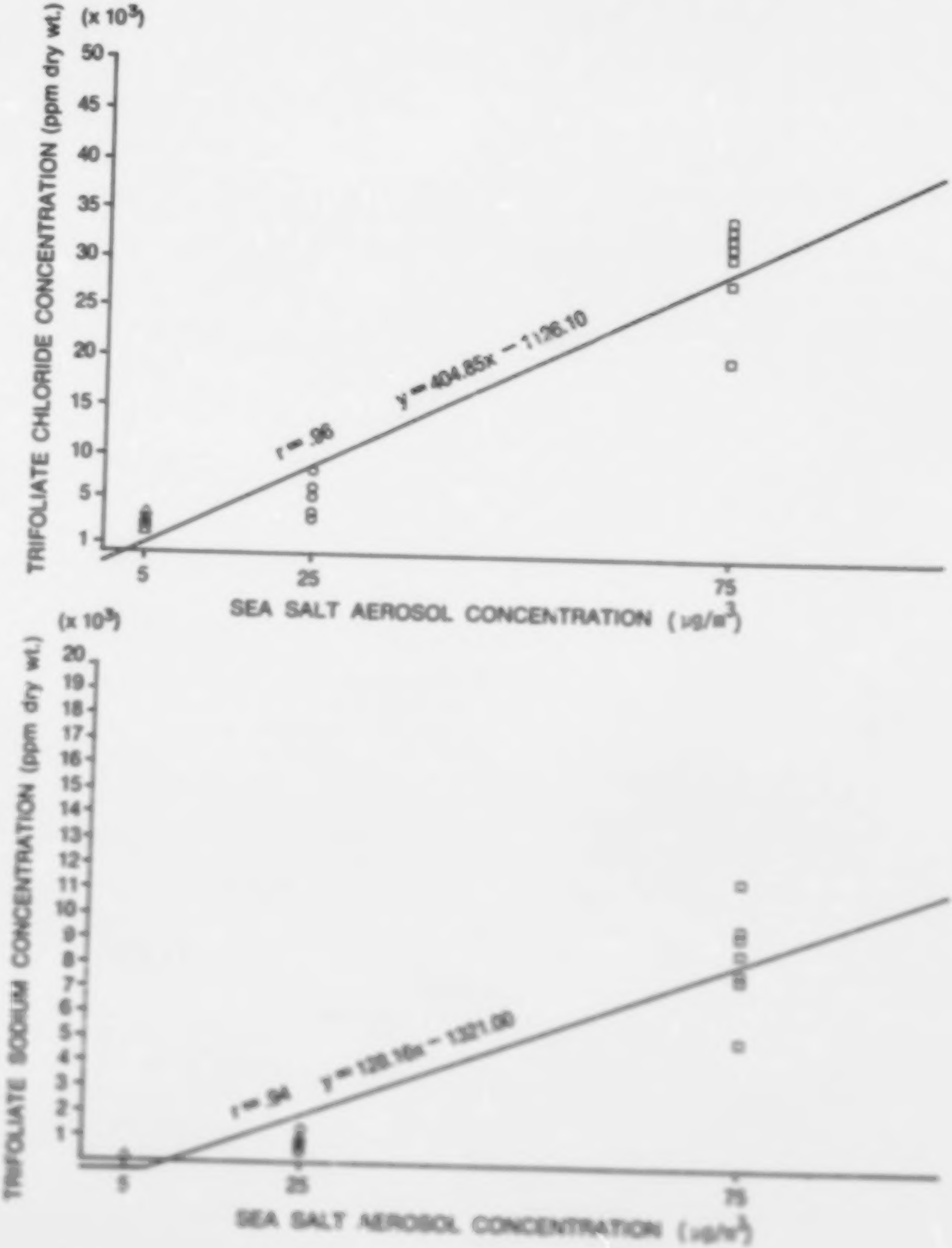

Figure 42. Foliar accumulation of sodium and chloride by bush bean trifoliate leaves exposed 100 hours to various concentrations of saline mist at age 5 weeks.

The incidence and severity of injury on the trifoliate leaves exhibited a corresponding increase with increases of trifoliate salt concentration (Tables 15-18). The severity of injury in the trifoliates increased rather uniformly as leaf Na$^+$ and Cl$^-$ concentration increased (Figure 43). The five weeks old plants probably best typify the relationship between salt accumulation and injury. The five week plants describe a near linear curve ($r = .77$ Na$^+$, $r = .74$ Cl$^-$; $n = 21$, $P < 0.05$) as severity of injury extends from the low levels encountered at the 5 μg/m^3 and 25 μg/m^3 treatments to the more extensive injury (average of 55% canopy trifoliate area injured) and higher accumulations (Na$^+$, 8,614 ppm; Cl$^-$ 30,140 ppm) at 75 μg/m^3.

Injury incidence showed an apparent, proportional trend between higher percentages of leaves injured with higher leaf salt concentrations. The five week old plants best illustrate the curvilinear relationship ($r > .98$ Na$^+$ and Cl$^-$, $n = 21$, $P < 0.01$) between incidence of trifoliate injury and leaf salt component accumulation (Figure 44). The slightly better correlation between incidence of injury and leaf salt accumulation is probably in a large part, due to the fact that accuracy of determining injury status is higher than estimating the areal extent of that injury when it occurs.

The higher concentration levels of the younger plants have probably shifted toward lower accumulations of Na$^+$ and Cl$^-$ as the ions were translocated and dispersed during post-exposure growth. The surface dispersion and translocation of ions would account for the relative steepening of the injury curve (Figure 44A), as the upper points shifted to the left. These particular curves for the one week and three week plants are more representative of relative concentration shift with injury than delineating a relationship between leaf salt concentration and severity of injury.

The level of salt accumulation that produced trace (> 0.5% upper trifoliate area) injury on the five week old plants was as low as approximately 100 ppm sodium and 2,800 ppm chloride. However, evaluating such small amounts of injury approaches the limits of detection and possible mimic effects were difficult to eliminate. For any detrimental growth effects, leaf salt accumulation had to be high enough to produce at least moderate amounts of foliar injury. The apparent toxicity limits of salt accumulations associated with moderate amounts of trifoliate injury (5-25% area) on the five week old plants ranged from approximately 900 to 12,000 ppm Na$^+$ and 6300 to 41,000 ppm Cl$^-$. for lower and upper limits of injury, respectively (Table 18).

TABLE 18. SHOWS PERCENT OF INJURED BUSH BEAN WITH RELATION TO TRIFOLIATE SODIUM AND CHLORIDE ACCUMULATION

Plant	$\mu g/m^3$	Percent Trifoliate Injury	Sodium	Chloride
One week	5	0	84.0	1148.0
	25	0.3	112.0	957.0
	75	18.7**	889.0	8630.0
Three weeks	5	0.7	204.0	2014.0
	25	1.7	496.0	6717.0
	75	17.6**	5820.0	32886.0
Five weeks	5	3.6	102.0	2789.0
	25	5.9	914.0	6254.0
	75	24.0**	12143.0	40700.0

Asterisks (**) indicate the injury column value within a particular weekly group is significantly different at 1% level of probability. Post-exposure conditions varied for the 3 ages of plants, do not directly compare the 3 ages of plants past the termination of exposure.

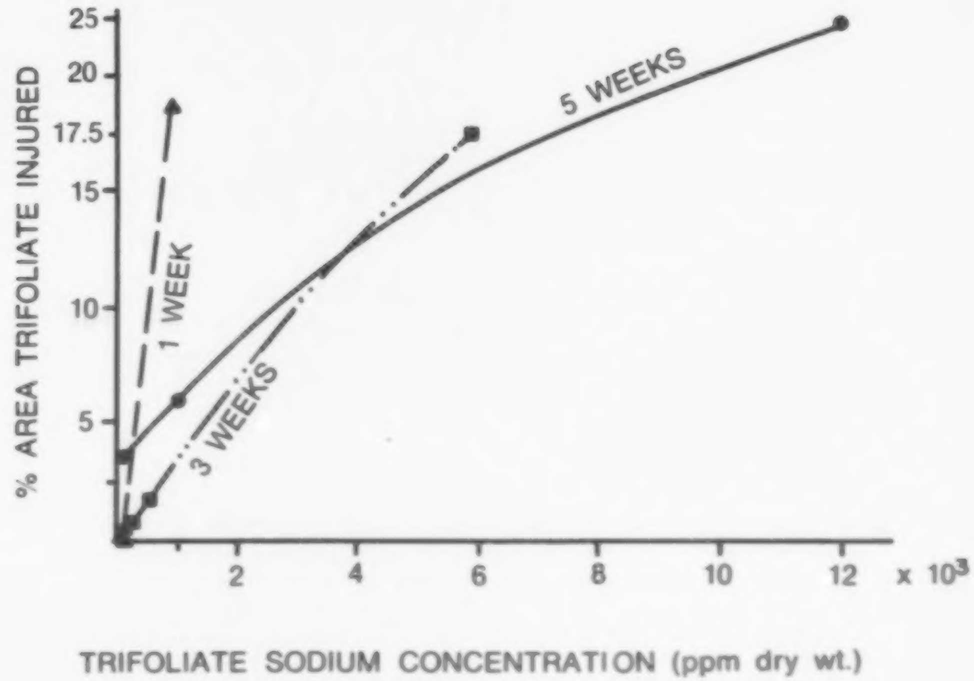

Figure 43 A Mean percent injured area of first three sets trifoliate leaves of three ages of sea salt aerosol exposed plants plotted against mature trifoliate Na$^+$concentration.

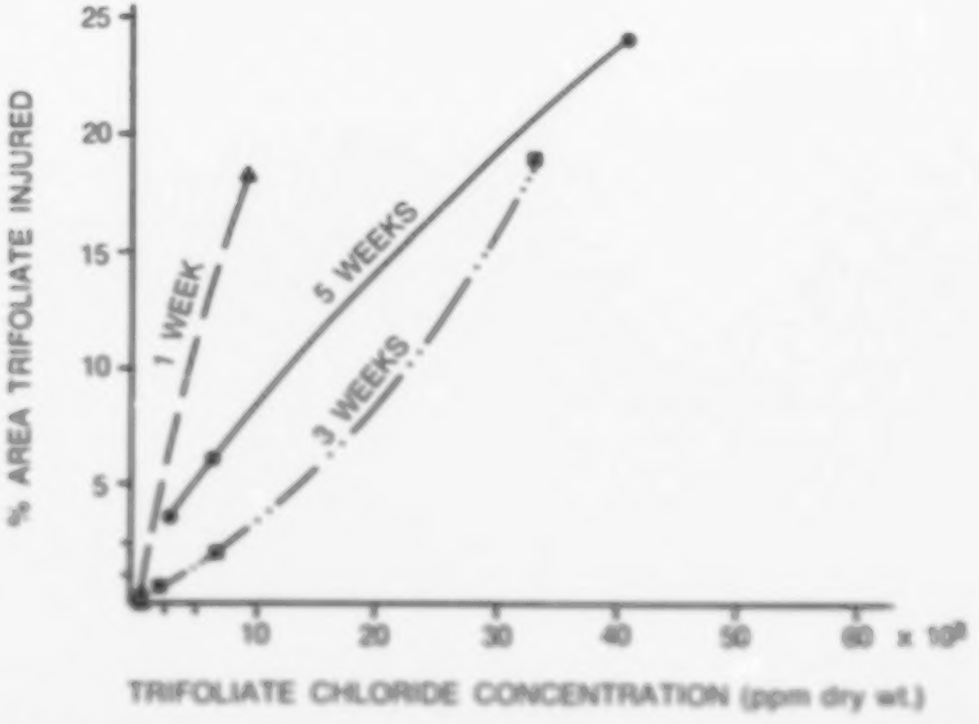

Figure 43 B Mean percent injured area of the first three sets of trifoliate leaves of three ages of sea salt aerosol exposed plants plotted against the trifoliate Cl-concentrations at maturity.

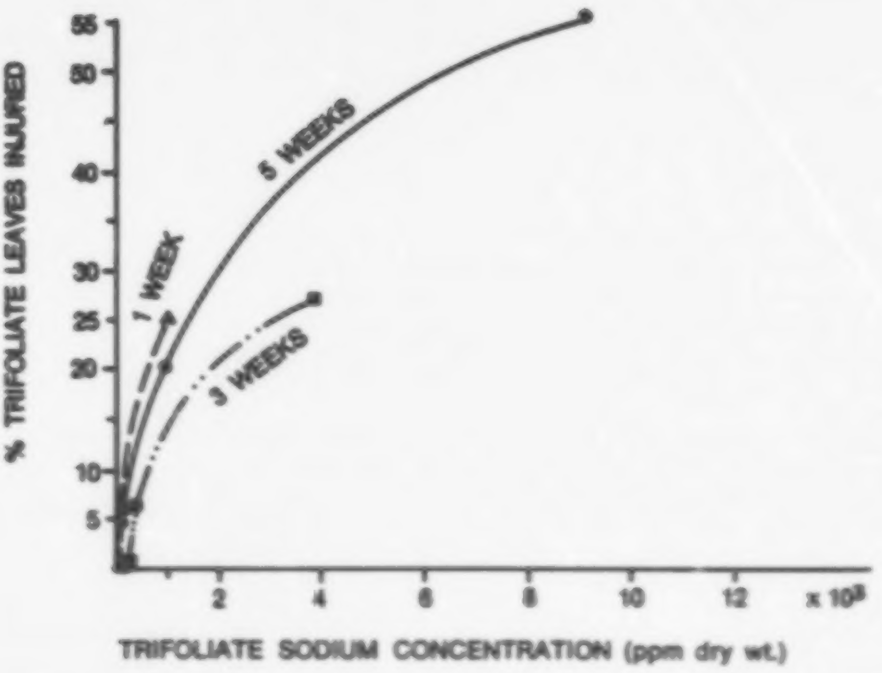

Figure 44a. Mean percent trifoliate leaves injured on three exposure ages of bush bean with varying Na$^+$accumulation in mature trifoliate leaves. (Exposure initiated at: —●— 5 weeks, —·—■—, 3 weeks, —▲— , 1 week.)

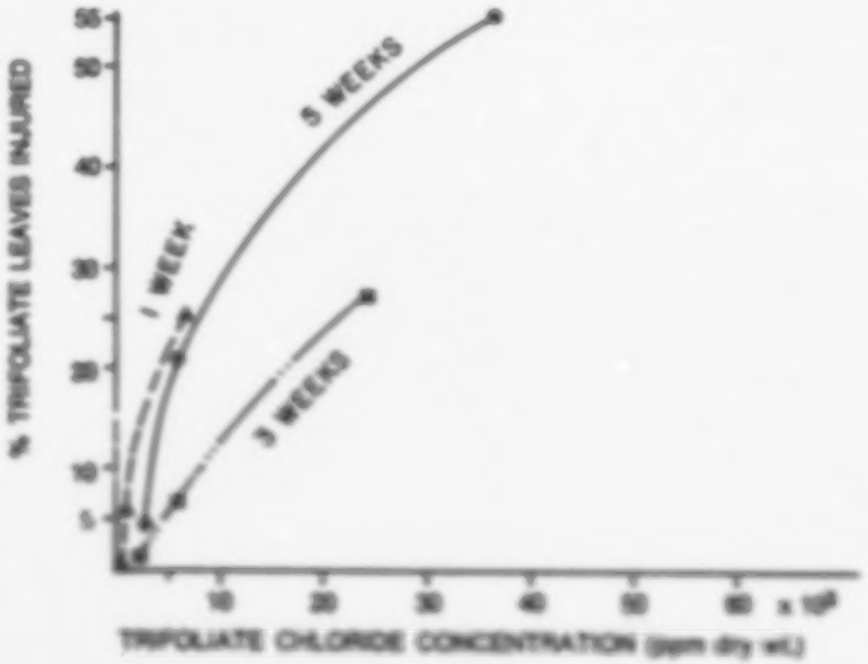

Figure 44b. Mean percent trifoliate leaves injured on three exposure ages of bush beans with varying C1-accumulation in trifoliate leaves after exposure to sea salt aerosol. (Exposure initiated: —●— 5 weeks, —■—, 3 weeks, —·—▲—, 1 week.)

Plant Growth Effects

Description--Growth effects attributable to salt aerosol in the controlled exposure studies were observed in the measurements of leaf weight and pod yield. In plants of the same age some growth characteristics, such as height and stem diameter, did not differ visually and were not examined further. The comparison of the total mass of plants of the same age showed no significant differences or trends.

Leaf Weight--In general, the growth effects of salt aerosol treatments on leaves were rather restricted or undetectable. The only age group which exhibited any vegetative response were the plants initially exposed at five weeks of age. The green and dry weights of the canopy trifoliates, the first trifoliates to emerge, showed a decreasing trend with increases in the salt aerosol treatment and a significant mass reduction ($P < 0.01$) at the 75 $\mu g/m^3$ concentration (Table 15). The green trifoliate mass decreased from 9.81 grams maximum average per plant at the 5 $\mu g/m^3$ concentration to only 5.10 grams at the 75 $\mu g/m^3$ treatment. In contrast, the younger plants did not show a similar trend. Whether this lack of similarity between age group response implied the absence of an exposure effect or represented a recovery capacity remained uncertain as the terminal sacrifice of mature plants prohibited simultaneous weight at exposure termination.

Pod Production and Yield--While the five week and three week old plants did not exhibit any detectable differences in productivity across the aerosol treatment gradient, the one week old plants experienced a pronounced reduction in pod weight and yield at the higher aerosol salt concentrations. Measurements showed generally fewer pods at the highest concentration treatment of 75 $\mu g/m^3$ (Figure 45).

Pod productivity differed by a factor of approximately two between the 5 $\mu g/m^3$ and 75 $\mu g/m^3$ treatments. The terminal pod productivity at the high concentration treatment increased rather abruptly while the other treatments changed little or declined slightly, with an increase in sample variance. The canopy trifoliate leaves of these plants had an average area injury of nearly 19% at termination of exposure, but did not show any visible symptoms of salt toxicity 29 days later at harvest. The 75 $\mu g/m^3$ treatment terminal pod productivity increase might represent a recooperative capacity similar to that shown by the leaves.

While the difference in one week plant pod productivity lessened by harvest, pod weight per plant remained significantly different. While the three and five week plants did not show any significant change with treatment, the one week old plant pod yield had a sharp reduction at even the intermediate treatment concentration of 25 $\mu g/m^3$ (Figure 46A,

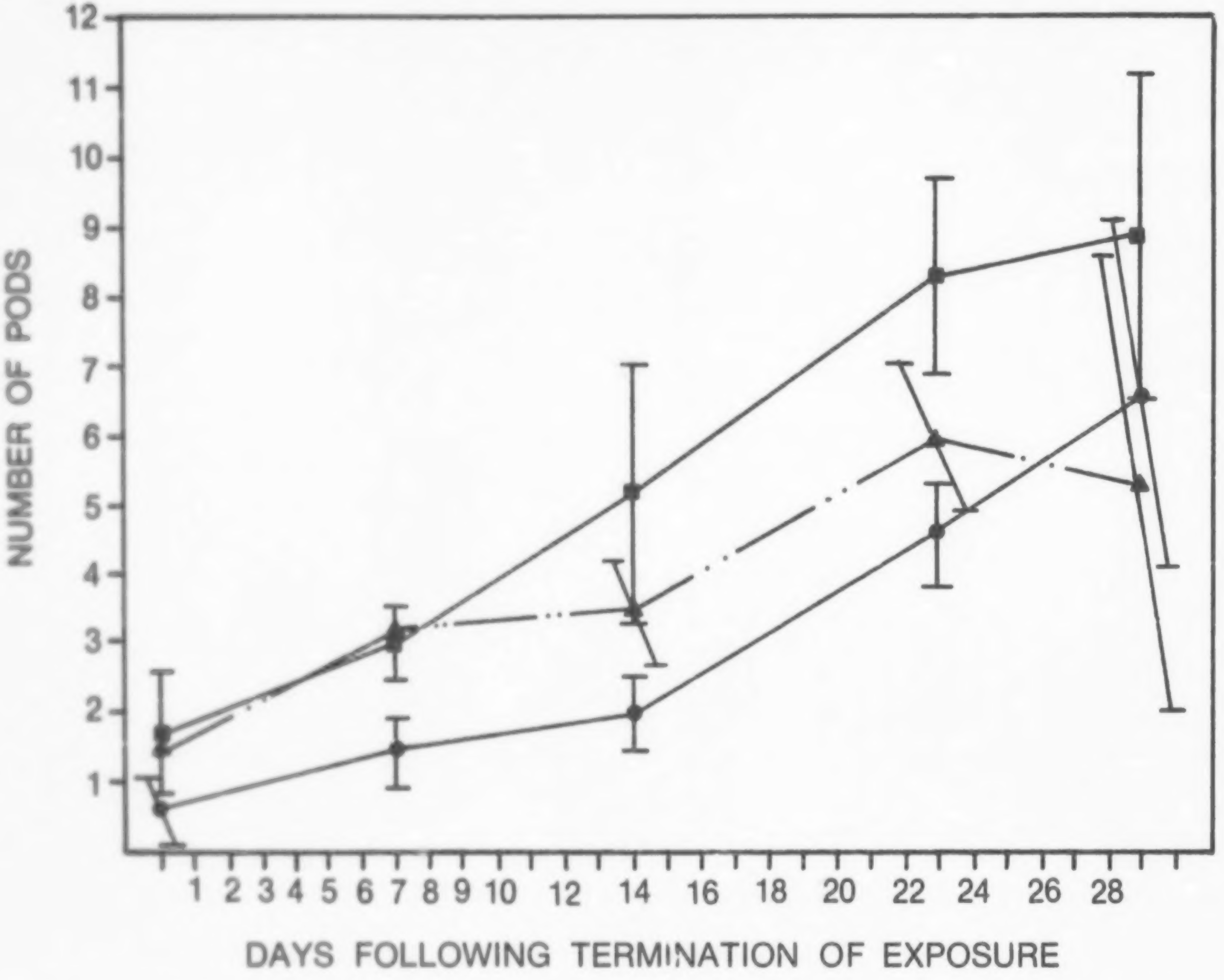

Figure 45. Average number of seed pods per plant (exposure initiated at age 1 week) exposed to three different airborne salt concentrations for 100 hours. Vertical lines indicate ± 1 least significant difference (LSD) at 5% level of probability. (□ 5 ug/m^3, △ 25 ug/m^3, ○ 75 ug/m^3; salt aerosol concentration.)

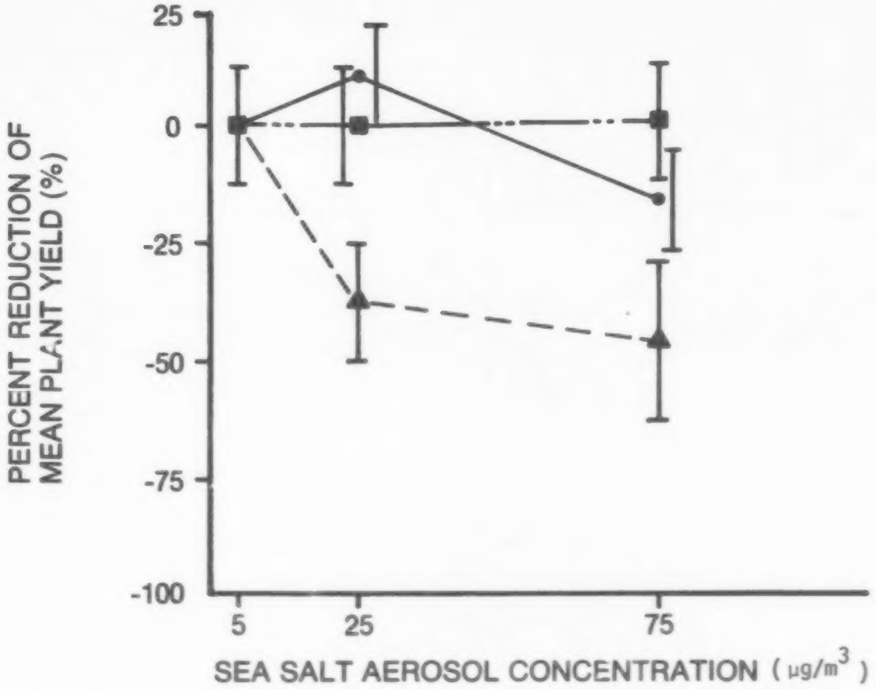

Figure 46 A Percentage reduction of mean plant pod dry weight (with seeds) of mature bush bean after exposure to three different sea salt aerosol concentrations at three stages of growth (plant age at initiation of exposure: —●— 5 weeks, —··■··· 3 weeks, — —▲— —1 week.)

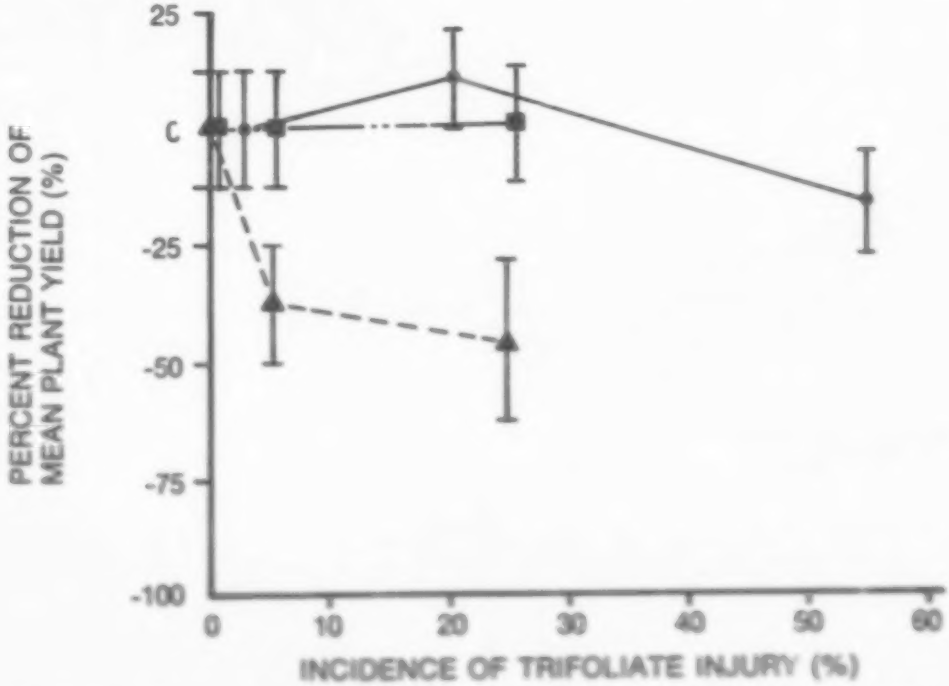

Figure 46 B. Percentage reduction of mean plant pod dry weight (with seeds) of mature bush bean (9 weeks) after 100 hours exposure to varying sea salt aerosol concentrations plotted against the percentage of leaves damaged on the plants. (Age at initiation of exposure: —●— 5 weeks,—■—·3 weeks,—▲—1 week.)

Table 19). The average plant pod dry weight from one week initial exposure plant of the 5 $\mu g/m^3$ treatment was 6.62 grams per plant at harvest. This yield was reduced nearly fifty percent, to 4.16 and 3.65 grams per pod at the 25 and 75 $\mu g/m^3$ treatments respectively. Much the same trend was preserved when pod yield was examined in relation to incidence of trifoliate leaf injury (Figures 46B and 47; Table 19). The older initially exposed plants had little change in pod yield, whereas the one week plants showed a pronounced decline with less than 5% injury incidence. Since leaf injury was strongly correlated to salt concentration, it was difficult to determine whether the reduction was attributable indirectly to leaf damage or a direct salt toxicity effect on the pods.

Ion Translocation--The sequential salt assay of the plants allowed some rather gross, comparative statements concerning direction and rates of ion movement. Tables 20 and 21 show composite Na+/Cl- ratios using the 5 $\mu g/m^3$ plants as background for the 3 and 5 week old plants. The composite salt ratios should approach that of seawater if the accumulated salts did not move differentially, i.e., the Na+/Cl- ratio should equal .55. This analysis permitted determination of differential rates of Na+ and Cl- translocation.

Sodium and chloride accumulations were highest in the stems and lowest in the leaves for both exposure ages at the 5 $\mu g/m^3$ aerosol concentration. The reverse was true of the other exposure concentrations with the salt gradient directed downward, sometimes with an order of magnitude difference (Tables 20 and 21). The sodium cation is in deficit when the salt ratio is less than .55, since excess chloride anion would have to be transported up a sizeable gradient for a consideraable distance. Successively comparing composite Na+/Cl- ratios among the plant parts for a given age and treatment indicated that sodium was the more mobile salt ion in the bean plant when salt aerosol was deposited on the leaves. The salt ratios were consistently less than .55 for leaves of all ages, while the stems and pods accumulated sodium with ratios greater than .55. The five week composite ratio of plant salt for the intact aboveground plant was .52 for the 75 $\mu g/m^3$ treatment. This suggested that the Na+ ion had moved from the leaves, but had not moved past the stems and pods. The 25 $\mu g/m^3$ treatment had an aboveground salt ratio of .48. While some sodium possibly moved to the roots, the ratio was too close to separate from experimental error. Since the whole roots could not be reclaimed for massing and chemical analysis, composite correlation was unreliable between the upper portion and root salt ratios. However, the average root salt ratios for all 5 weekly plants were nearly identical, about 1000 sodium ppm to 400 chloride ppm (Table 15).

The three week old plants had a 16 day post-exposure period and showed a more pronounced, but similar leaf sodium deficit as the five week old plants. The salt ratio for the aboveground portion of

TABLE 19. THREE STAGES OF BUSH BEAN EXPOSED TO THREE SALT DEPOSITIONS WITH RELATION TO SEEDS AND PODS FORMATION

Plant	$\mu g/m^3$	Percent Leaf Injury	Average No Pods	Average No Seeds	Pods & Seeds Green Weight gr	Dry Weight gr
One week	5	0	8.29	33.71	70.37	6.62
	25	0.3	6.29	23.86	33.05**	4.16*
	75	18.76**	6.57	24.29	39.30**	3.65*
Three weeks	5	0.7	4.0	13.37	23.80	4.16
	25	1.7	3.57	12.14	23.22	4.16
	75	17.6**	3.86	12.43	22.14	4.20
Five weeks	5	3.6	3.14	10.43	24.36	3.48
	25	5.9	3.71	12.71	19.31	2.94
	75	24.0**	2.43	9.29	19.31	2.94

Asterisks in a column indicate significant difference from nonasterisk values at * $P < 0.005$;** $P < 0.01$ for that weekly group indicated by analysis of variance. Post-exposure conditions varied for the 3 ages of plants exposed, do not directly compare the 3 ages of plants past the termination of exposure.

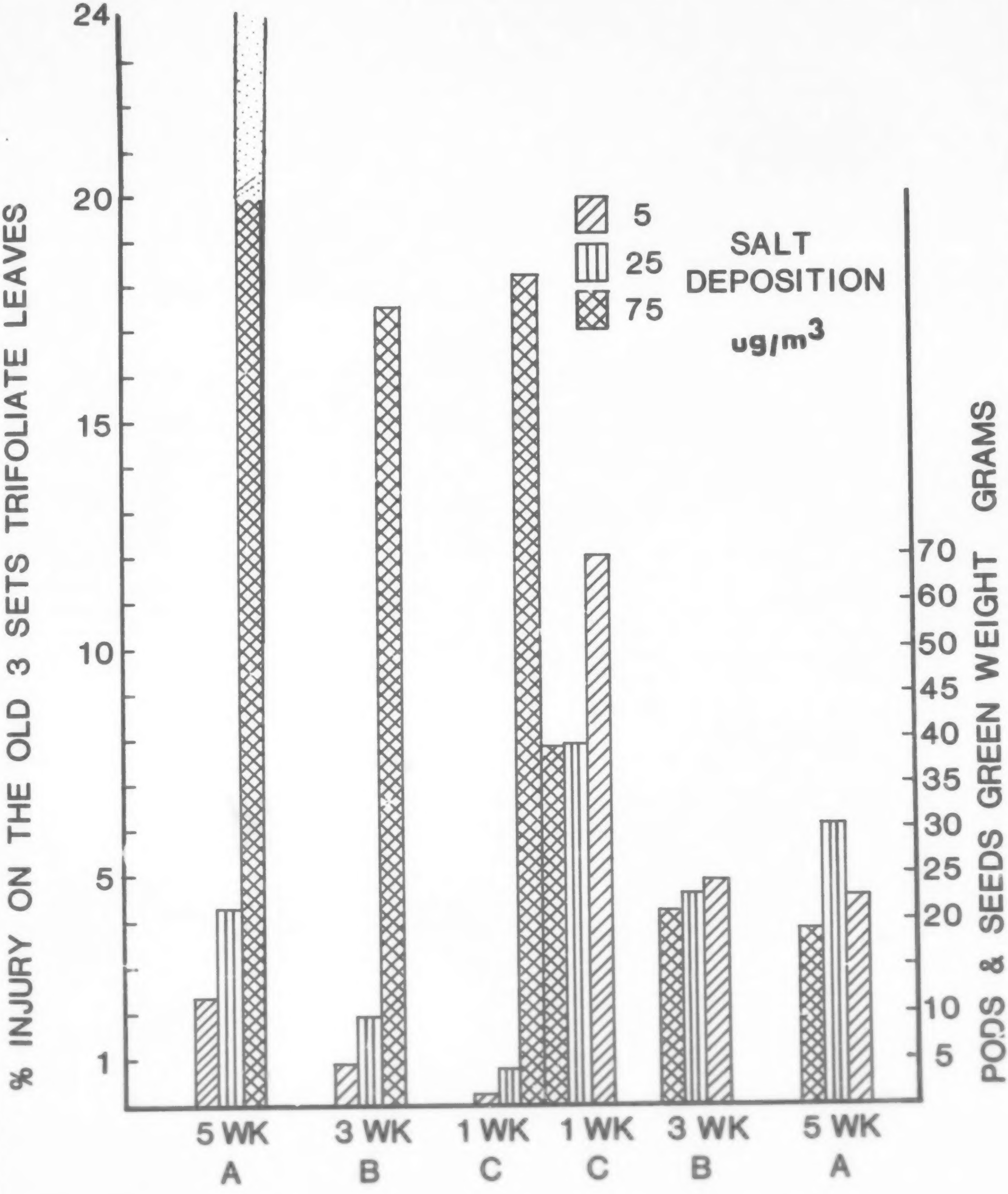

Figure 47. PODS & SEEDS WEIGHT WITH RELATION TO INJURY ON PLANTS

TABLE 20. NORMALIZED Na$^+$/Cl$^-$ RATIO OF APPROXIMATE NET AEROSOL CONTRIBUTION FOR COMPOSITE SEGMENTS OF BUSH BEAN PLANTS WHICH WERE EXPOSED AS WHOLE PLANTS TO SEA SALT AEROSOL FOR 100 HOURS. PLANTS WERE 5 WEEKS OLD AT INITIATION OF EXPOSURE. Na$^+$/Cl$^-$ RATIO OF SEA WATER IS .55.

	25 μg/m^3	Na$^+$ Status	75 μg/m^3	Na$^+$ Status
First three sets of trifoliate leaves	.23	-Na$^+$	.32	-Na$^+$
Remaining trifoliate leaves	.28	-Na$^+$	.31	-Na$^+$
Stem	3.17	+Na$^+$	2.04	+Na$^-$
Pod (with seeds)	5.06	+Na$^+$	4.69	+Na$^+$
Intact standard portion of plant (plant less roots)	.48	±Na$^+$	.52	±Na$^+$

TABLE 21. NORMALIZED Na$^+$/Cl$^-$ RATIO OF APPROXIMATE NET AEROSOL CONTRIBUTIONS FOR COMPOSITE SEGMENTS OF BUSH BEAN PLANTS WHICH WERE EXPOSED AS WHOLE PLANTS TO SEA SALT AEROSOL FOR 100 HOURS. PLANTS WERE 3 WEEKS OLD AT INITIATION OF EXPOSURE. Na$^+$/Cl$^-$ RATIO OR SEA SALT AEROSOL IS .55

	25 μg/m^3	Na$^+$ Status	75 μg/m^3	Na$^+$ Status
First three sets of trifoliate leaves	.03	-Na$^+$	.17	-Na$^+$
Remaining trifoliate leaves	.08	-Na$^+$	.14	-Na$^+$
Stem	7.25	+Na$^+$	1.48	+Na$^+$
Pod (with seeds)	2.10	+Na$^+$	11.51	+Na$^+$
Intact standing portion of plant (plant less roots)	.29	-Na$^+$	.44	±Na$^+$

the 75 μg/m^3 treatment plants was .44. The 25 μg/m^3 composite salt ratio was .29 (Table 21) indicating the likelihood that some sodium had been moved to the root system before the chloride anion. In general, the roots had a net increase in sodium concentration across the aerosol gradient for the three week old plants (Table 16). However, the lack of a complete and representative root analysis precluded the determination of the ultimate fate of excess salts. Although the soil analysis did not show measurable increases across the aerosol gradient for any of the age groups, the watering technique allowed ion loss to the plant containers. Considering experimental limitations, the major conclusion can only be that the sodium cation was translocated at a comparatively faster rate than the chloride anion in the aboveground portion of exposed bean plants. This is in essential agreement with foliar applied radioactive tracer studies done with Na^{22} and Cl^{36} on bush bean (30).

SECTION VIII

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SECTION IX

APPENDIX

SODIUM CONCENTRATION (PPM DRY WEIGHT) OF MANGROVE LEAVES SAMPLED AT TURKEY POINT, FLORIDA

	Period		
	Prior	During	After
	Na+		
SITE 2	1170	2180	1820
	1672	2130	1700
	1710	1200	4000
	1230	2470	3430
	950	3780	2170
	1270	4340	
	1341	3870	
	2240	3680	
	1180		
	4280		
	2320		
SITE 3	316	3640	4060
	1320	375	3850
	516	439	1420
	616	396	
	10180	3320	
	451	9910	
	395	810	
	1620	570	
	1380	270	
		1950	
SITE 1 km NORTH OF 3	22900	11200	3620
	22500	10900	2160
	3480	11400	2630
	3360	12050	
	11100	3870	
	11100	2630	
		7060	
		3450	
		1790	
SITE 4	1660		
	1499		
	1120		
	2980		
SITE 7	3910	10000	27100
	2780	15500	4140
	1550	36700	3440
	15100	23000	2010
	17000	5660	
	11700	1990	
	5410	2470	

SOIL SAMPLES TAKEN FROM TURKEY POINT

			ppm			
Site	Period	pH	NO_3	P	Ca	Cl
No. 4	Prior	7.8	9	2	75	20
		7.9	8	20	100	250
		8.2	.12	6	50	400
		7.9	8	25	100	350
		7.75	11	25	150	700
		8.0	3	20	100	500
	During	7.9	10	18	75	210
		7.9	.5	4	70	450
		7.9	5	40	200	1400
	After	7.9	5	25	200	1000
		7.8	5	25	150	1150
		7.9	1	79	250	1100
		7.9	11	30	300	1150
		8.0	7	25	100	500

Missing values are indicated by -1

SOIL SAMPLES TAKEN FROM TURKEY POINT

Site	Period	pH	ppm NO_3	ppm P	ppm Ca	ppm Cl
(1/2 mi. North of Site No. 4 .8 km)	Prior	7.8	9	2	75	20
		7.9	8	20	100	250
		8.2	.2	6	50	380
		7.6	15	65	200	750
		7.5	15	35	140	800
		8.0	3	20	100	450
	During	7.7	18	35	125	500
		7.95	.3	3	70	490
		7.6	12	40	150	600
	After	7.8	12	65	200	1075
		7.5	15	120	750	4500
		7.7	.4	25	100	650
		7.8	14	25	250	505
		7.8	10	30	150	1000

SOIL SAMPLES TAKEN FROM TURKEY POINT

			ppm			
Site	Period	pH	NO_3	P	Ca	Cl
(1 mi. North of Site No. 4 1.6 km North of)	Prior	7.8	9	2	75	20
		8.0	9	35	100	120
		8.25	.3	4	40	190
		7.9	6	30	75	290
		7.9	9	25	125	200
		7.9	2	16	100	70
	During	7.8	8	25	100	85
		8.1	.3	2	40	50
		7.8	4	30	75	250
	After	7.9	1	22	150	400
		7.7	4	35	150	700
		8.0	< .1	20	75	90
		7.9	5	30	200	340
		8.0	1	16	75	65

SOIL SAMPLES TAKEN FROM TURKEY POINT

			ppm			
Site	Period	pH	NO_3	P	Ca	Cl
(1 1/2 mi. North of Site No. 4 2.4 km)	Prior	7.8	9	2	75	20
		7.8	11	25	100	150
		8.3	.1	2	40	130
		7.7	16	30	125	210
		7.7	14	30	150	250
		7.7	7	20	100	80
	During	7.8	10	25	100	80
		8.0	< .1	2	40	50
		7.9	< .1	4	40	70
	After	7.8	9	25	400	490
		7.8	8	30	155	300
		8.0	2	10	75	100
		7.7	2	14	175	310
		7.9	7	16	75	100

WATER SAMPLES TAKEN FROM TURKEY POINT

Site	Period	pH	ppm Chloride
No. 2 two miles downwind from the cooling tower	Prior	8.1	450
	During	8.2	300
		7.9	219
	After	8.4	260
		8.1	440
		8.2	340
		7.9	400
2.4 km North of Site No. 2	Prior	8.1	55
	During	8.2	48
		7.9	70
	After	8.2	210
		insufficient water	
		8.3	140
		7.9	145
1.6 km North of Site No. 2	Prior	8.1	65
	During	8.25	60
		8.0	375
	After	8.2	500
		8.2	465
		8.3	160
		no water	
No. 2 0.8 km North of EPA Site	Prior	8.0	480
	During	8.25	230
		7.8	300
	After	8.2	310
		8.2	1050
		8.2	270
		no water	

INTRODUCED SOIL SAMPLE PH AND SODIUM MEASUREMENTS AT TURKEY POINT SITES

Site	Period	pH	Na^+ ppm
No. 2	Prior	7.0	16.0
		7.5	32.19
		7.5	18.40
		6.6	91.96
	During	7.5	45.99
		7.9	29.89
No. 3	Prior	7.0	16.0
		7.1	4.6
		7.3	4.6
	During	8.0	22.9

Sodium and Chloride Concentrations of Cultivar Plants Exposed at Turkey Point, Florida, 15-74, 1974

Julian Date Date set out - date Collected	EPA Site Number	BEAN		CORN	
		Sodium (ppm)	Chloride (ppm)	Sodium (ppm)	Chloride (ppm)
15-23	1	1350	15400	1370	19600
		1630	15100	1500	22100
		1530	15100	1140	26200
15-23	2	301	11500	153	14300
		234	9260	102	16500
		378	9030	174	17200
15-23	3	142	12900	80	17900
		140	11800	163	21400
		98	10300	197	18200
15-23	5	143	21700	169	11200
		176	11100	195	17600
		155	7070	124	17000
15-23	7	323	8750	265	16300
		240	9730	261	18300
		265	8460	364	16500
15-23	8	150	9970	153	15500
		153	7310	165	17500
		196	9420	128	18900
15-23	9	270	7880	160	15300
		281	10600	85	15200
		157	15300	117	14700
15-30	1	5360	45300	2850	27300
		4530	29400	2940	22600
		5910	35400	2570	21800
15-30	2	759	10000	545	23600
		509	8350	431	19600
		741	16900	846	19100
15-30	3	205	11500	150	10100
		319	12200	119	13600
		212	13000	145	19700
15-30	9	434	16100	380	17700
		505	16500	507	27100
		521	12400	545	15000
15-37	1	2920	25100	3640	28300
		4480	42400	3530	24100
		3570	21300	3320	24000
15-37	2	389	17000	277	15100
		330	10200	331	18000
		326	14300	319	17700
15-37	3	1100	20200	1080	16800
		1720	11300	982	17300
		1100	14100	614	11400

Julian Date Date set out - Date collected	EPA Site Number	BEAN		CORN	
		Sodium (ppm)	Chloride (ppm)	Sodium (ppm)	Chloride (ppm)
15-37	9	1370	16300	1220	21600
		1230	14800	994	21900
		923	14100	920	19700
15-74	3	140	7300	224	14100
		139	14700	170	13900
		197	14300	368	6780
		270	7540	334	8830
		147	17200	264	7380
		208	15200	186	7860
15-74	7	1870	15900	1480	13600
		1760	10700	2070	16600
		2210	21100	1510	14500
		1940	12300	1420	14000
		992	18300	939	10200
		1130	17600	2030	16300
23-30	1	4160	14300	3350	16800
		3170	13400	1700	15600
		3590	13200	3090	15000
23-30	2	843	11500	557	12200
		785	9160	598	14600
		779	8590	384	16200
23-30	3	272	7340	242	10500
		325	4340	270	15500
		420	13100	260	15400
23-30	9	591	10300	383	14600
		646	12100	339	13300
		620	12300	313	14300
23-37	1	4960	15500	3950	19800
		4220	15300	3700	20400
		4710	14600	3480	20100
23-37	2	428	9430	372	13200
		352	8500	301	11700
		454	12200	385	9590
23-37	3	1100	9500	907	11800
		1000	9130	593	12900
		993	12100	991	7460
23-37	9	1130	11500	447	14300
		875	10600	539	13800
		448	8930	418	10900
23-44	1	2890	11700	5440	16900
		4320	17100	3870	18200
		3230	1000	3930	17500

Julian Date Date set out - Date collected	EPA Site Number	BEAN Sodium (ppm)	BEAN Chloride (ppm)	CORN Sodium (ppm)	CORN Chloride (ppm)
23-44	2	1120	12700	907	8980
		1130	4010	803	9030
		1010	12100	1310	17400
23-44	3	529	8030	610	8190
		410	9440	483	12000
		482	12500	545	15100
23-44	9	1250	12100	783	12400
		1400	14300	716	13900
		950	10600	706	14100
30-37	1	773	7210	523	12500
		617	7670	1200	15200
		623	9030	798	15500
30-37	2	225	6530	198	14700
		172	7230	282	20800
		167	6760	163	14600
30-37	3	479	7190	1080	16800
		324	8540	982	17300
		264	5670	614	11400
30-37	8	162	7590	203	10600
		251	7060	212	15100
		189	6450	158	9460
30-37	9	346	6730	283	15900
		440	6440	293	15000
		333	7370	206	11800
30-44	1	821	7180	672	14800
		596	8280	918	15300
		784	8740	840	15000
30-44	2	275	6770	333	11200
		396	6610	472	10800
		399	6790	468	14900
30-44	3	166	6260	217	15900
		201	6400	223	11600
		190	9460	265	13000
30-44	9	291	7840	277	10100
		297	7640	222	8590
		326	8240	522	14700
30-51	1	3180	24000	2790	13500
		4530	20400	3410	12900
		3180	17100	2960	14200
30-51	2	358	9630	513	12600
		643	9500	420	9760
		522	9010	650	10800
30-51	3	119	8200	124	11400
		111	8030	144	13100
		132	10900	132	12900

Julian Date DAte set out - Date collected	EPA Site Number	BEAN		CORN	
		Sodium (ppm)	Chloride (ppm)	Sodium (ppm)	Chloride (ppm)
30-51	9	291	8370	411	11200
		365	7990	406	16900
		324	11200	301	14200
37-44	1	696	12900	558	12600
		1000	12600	600	14700
		645	13800	687	21600
37-44	2	293	11800	665	11800
		331	9760	837	9760
				665	22500
37-44	3	293	13600	425	22600
		196	12800	262	15300
		777	9900	368	21400
37-44	9	292	11500	531	22100
		520	14900	364	18100
			12000	312	16100
37-51	1	3200	19400	2870	20100
		1850	29500	1430	15200
		2050	16700	2580	19400
37-51	2	552	16900	175	16500
		371	12000	233	20300
				245	18000
37-51	3	136	15400	175	16500
		152	12000	233	20300
		109	12200	245	18000
37-51	9	431	13700	270	15700
		300	12400	250	16700
		301	13200		
37-58	1	1900	20600	3710	13700
		3080	17600	3450	16600
		2861	21100	3110	13200
37-58	2	627	15500	627	15500
		685	13700	695	13700
		733	12700	733	12700
37-58	3	126	14700	197	18500
		82	14900	337	15700
		116	14400	211	14700
37-58	9	301	14800	599	14600
		528	14700	581	15000
		360	2740	562	11700
52-58	1	176	2470	255	13500
		191	2690	277	9580
		133	2850	233	8170
		156	2880	272	10400
		208	3100	135	13800

Julian Date Date set out - Date collected	EPA Site Number	BEAN		CORN	
		Sodium (ppm)	Chloride (ppm)	Sodium (ppm)	Chloride (ppm)
52-58	2	179	2270	103	10400
		191	2460	220	11500
		161	2760	814	11700
		174	4630	239	10000
		210	2800	333	4770
52-58	3	194	2540	295	14800
		161	1960	362	12700
		129	3130	498	12900
		66	1170	200	5390
52-58	9	267	3260	308	13100
		152	3730	217	13700
		137	1890	292	6460
				191	10400
52-65	1	2350	16700	836	18200
		961	13700	1560	14700
		1680	15300	1240	16300
		2550	16700	1140	13100
		674	12900	1550	18100
52-65	2	244	8010	197	16000
		223	15200	340	12200
		225	9010	190	18500
		201	1090	224	9740
		214	9940	180	12200
52-65	3	97	7960	72	14800
		113	8980	115	16400
		62	10300	1070	16300
		94	9080	80	17100
		78	10580		
52-65	7	744	10900	582	16700
		433	9390	424	20600
				729	18600
52-65	9	417	9970	277	17300
		370	12300	429	16400
		298	9950	358	18100
		319	220	177	17900
				201	15400
52-74	1	5910	26600	2090	20700
		3610	22300	2450	27900
		3390	21500	2120	26400
		3460	19700	2380	19600
		4060	21100	2570	25200
52-74	2	463	7480	314	12300
		453	6090	328	16200
		514	15400	647	15400
		356	14800	533	15100
		428	12200	515	16900

Julian Date	EPA Site	BEAN		CORN	
Date set out - Date collected	Number	Sodium (ppm)	Chloride (ppm)	Sodium (ppm)	Chloride (ppm)
52-74	3	220	7610	124	11900
		194	7450	97	12500
		214	8820	76	14000
		289	7430	70	13700
		194	8820	67	15500
52-74	9	619	20400	365	11200
		559	11600	358	15900
		631	12700	501	17500
		616	9390	266	15700
		621	12500	248	18200
59-74	1	1210	18300		
		1180	14300		
		970	14700		
		1200	20300		
		1520	12600		
		1700	16000		
		974	16300		
		1200	13100		
		846	12700		
59-74	2	579	17100		
		448	11900		
		520	16500		
		522	14500		
		622	15100		
		304	17600		
		567	15900		
		448	13600		
		413	16700		
59-74	3	187	12400		
		236	9860		
		318	12800		
		214	11000		
		307	9460		
		225	9620		
		213	11000		
		250	9740		
		188	11900		
		214	13100		
59-74	9	309	9030		
		380	10300		
		499	11700		
		437	9730		
		334	13800		

Julian Date Date set out - Date collected	EPA Site Number	BEAN		CORN	
		Sodium (ppm)	Chloride (ppm)	Sodium (ppm)	Chloride (ppm)
59-74	9	396	14000		
		426	10000		
		309	10300		
		494	10800		
		395	12100		

Cooling Tower and Powered Spray Module (PSM) Operations Log With Periods of Critical Wind for Introduced Plant Sites During Phase II

Date	Time & Hours Cooling Tower Operation		Time & Hours Critical Wind cat. 4,5 Sta. 1,2,3		Time & Hours Critical Wind Cat. 1,2,3 Sta. 7		Time & Hours Critical Wind Cat. 2,3,4 Sta. 9		Time & Hours Spray Module Operation		Time & Hours Critical Qind Cat. 4,5 Sta. 1,2.3		Time & Hours Critical Wind Cat. 1,2,3 Sta. 7		Time & Hours Critical Wind Cat.2,3,4 Sta. 9		24 Hr. Precip.	R.H.% 0900
Jan.																		
15	0800-1000	2	--	0	--	0	--	0	--	0	--	0	--		--	0	0.86	99
16	0800-1000	2	0800	1	--	0	--	0	--	0	--	0	--	0	--	0	0	84
17	0800-1000	2	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	91
18	0800-1000	2	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	90
19	0800-1000	2	0900	1	--	0	--	0	--	0	--	0	--	0	--	0	0.03	69
20	0800-1000	2	0800-1000	2	--	0	--	0	--	0	--	0	--	0	--	0	0	64
21	0800-1400	6	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	68
22	1300-1630	3.5	1300-1600	3.5	--	0	1300-1400 1600	3	1100-1600 1700-1800	6	1100-1800	6	--	0	--	0	0	90
23	1030-1500	4.5	1000-1500	4.5	--	0	1000 1200-1500	4	1700-1730	.5	1700	.5	--	0	--	0	0	69
24	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	77
25	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	72
26	1200-1730	5.5	1200-1600	5	1700	.5	--	0	--	0	--	0	--	0	--	0	0	68
27	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	67
28	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	67
29	--	0	--	0	--	0	--	0	1000-1800	8	--	0	--	0	--	0	0	76
30	--	0	--	0	--	0	--	0	0900-1900	10	--	0	--	0	--	0	0	79
31	--	0	--	0	--	0	--	0	0830-1900	10.5	1400-1800	5	1200-1300	2	1300-1400	2	0	87
Feb.																		
1(32)	--	0	--	0	--	0	--	0	C330-1910	10.6	1600-1700 1900	2.17	1100-1500	5	1300-1500	3	0	83
2(33)	--	0	--	0	--	0	--	0	0900-1330	4.5	--	0	--	0	--	0	0	79
3(34)	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	63
4(35)	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	85
5(36)	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	73
6(37)	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	66
7(38)	--	0	--	0	--	0	--	0	1130-2400	12.5	--	0	--	0	--	0	0	82
8(39)	--	0	--	0	--	0	--	0	2400-2400	24	--	0	--	0	--	0	0	89
9(40)	--	0	--	0	--	0	--	0	2400-2400	24	--	0	--	0	--	0	0	65
10(41)	--	0	--	0	--	0	--	0	2400-2400	24	--	0	--	0	--	0	0	36
11(42)	--	0	--	0	--	0	--	0	2400-2400	24	1500-1600	2	1100-1400	4	1100-1500	5	0	47
12(43)	--	0	--	0	--	0	--	0	2400-2400	24	1900-2000	2	1200-1800	7	1800-2000	3	0	63
13(44)	--	0	--	0	--	0	--	0	2400-2400	24	1200	1	1100-1600	6	1500-1700	3	0	64
14(45)	--	0	--	0	--	0	--	0	2400-2400	24	1600-2200	7	1100-1500	5	1500-1700	3	0	77
15(46)	--	0	--	0	--	0	--	0	2400-2400	24	0300	3	1100-1300	3	1100-1200	3	0	77
16(47)	--	0	--	0	--	0	--	0	2400-1000	10	1400-1500	0	--	0	1400	0	0	71
17(48)	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	70
18(49)	--	0	--	0	--	0	--	0	1000-1900	9	1400-1600 1800-1900	5	1100-1300	3	--	0	0	62
19(50)	1045-1730	6.8	--	0	--	0	--	0	--	0	--	0	--	0	--	0	0	73
20(51)	0945-1915	9.5	1200-1800	7	1100 & 1900	1.25	1200-1900	8.25	--	0	--	0	--	0	--	0	0	90
21(52)	0930-2400	14.5	0900-1400 1900-2400	8.5	--	0	0900	.5	--	0	--	0	--	0	--	0	0	92
22(53)	2400-2400	24	2400	1	--	0	--	0	--	0	--	0	--	0	--	0	0	80
23(54)	2400-2400	24	2000-2400	4	1300-1900	7	1600-2200	7	--	0	--	0	--	0	--	0	0	62
24(55)	2400-2400	24	2400-0100	2	1200-1300	2	1300	1	--								0	64
25(56)	2400-2400	24	--	0	2400	1											0.02	67

Date	Time & Hours Cooling Tower Operation		Time & Hours Critical Wind cat. 4,5 Sta. 2,3		Time & Hours Critical Wind Cat. 1,2,3 Sta. 7		Time & Hours Critical Wind Cat. 2,3,4 Sta. 9		Time & Hours Spray Module Operation	Time & Hours Critical Qind Cat. 4,5 Sta. 1,2,3	Time & Hours Critical Wind Cat. 1,2,3 Sta. 7	Time & Hours Critical Wind Cat.2,3,4 Sta. 9	24 Hr. Precip.	R.H.% 0900
Jan.														
26(57)	2400-2400	24	--	0	--	0							0	59
27(58)	2400-2400	24	--	0	1500-2400	9	2100	2					0	82
28(59)	2400-2400	24	0900-1000 1200-1300	4	24-06, 08, 1100,14-23	19	2300-2400 2400-0600 0800-2200	22					0	75
March														
1(60)	2400-2400	24	--	0	1200-2400 0100-0700	19	1300-1800	8					0	77
2(61)	2400-2400	24	2400-0100 1300,1500	4	0200-0500 0800-0500 1400,16-2300	17	2200-2400 2400-0400 0800-1200 1400-2400	20					0	66
3(62)	2400-2400	24	0100-0300 000-1800	4	0200, 0500- 1700 1900-2400	19	2400-2400	24					0	65
4(63)	2400_2400	24	0100-0600 0900-1300 2200-2400	13	0200-0800 1400-2100	10	2400-2400	24					0	65
5(64)	2400-2400	24	2400-0200 0900-1500	14	0800 1600-2400	9	2400-0400 0700-2400	22					0	80
6(65)	2400-2400	24	0100-0200	12	0200-2400	22	2400-2400	24					0.03	76
7(66)	2400-2400	24	0100-1200	12	2400 1300-2300	12	2400-0500 07-2400	23					0	75
8(67)	2400-2400	24	2400-1500 2100-2400	19	1600-2000	5	2400-2000	24					0	71
9(68)	2400-2400	24	2400-2300	24	--	0	2400-2400	24					0	67
10(69)	2000-2400	24	0100-2400	23	2400	1	2400-0100 0800-1400 1600-2400	17					0	59
11(70)	2400-2400	24	0100-0400 1200-2400	16	1100	1	2400-0300 1100 1300-1400	7					0	76
12(71)	2400-2400	24	0100	1		0							0	82
13(72)	2400-2400	24	--	0		0							0	92
14(73)	2400-2400	24	1800-2400 2000-2400	5	1000-1700 1900	9	1300-2400	11					0	87
15(74)	2400-2000	24	2000-0200 1100-2400	21		0	1200-1500	4					0	75